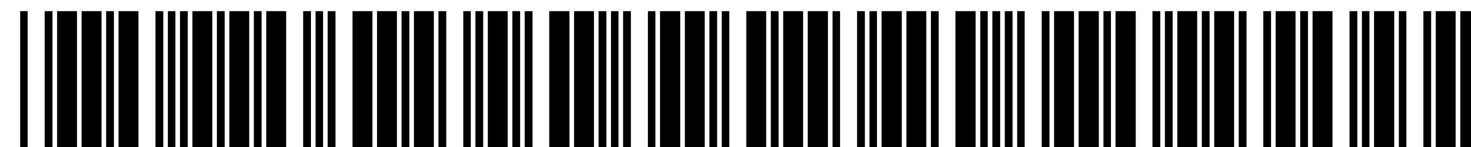

US010741572B2

(12) **United States Patent**
Sharangpani et al.

(10) **Patent No.: US 10,741,572 B2**
(45) **Date of Patent: Aug. 11, 2020**

(54) **THREE-DIMENSIONAL MEMORY DEVICE HAVING MULTILAYER WORD LINES CONTAINING SELECTIVELY GROWN COBALT OR RUTHENIUM AND METHOD OF MAKING THE SAME**

(71) Applicant: **SANDISK TECHNOLOGIES LLC**, Plano, TX (US)

(72) Inventors: **Rahul Sharangpani**, Fremont, CA (US); **Raghuveer Makala**, Campbell, CA (US); **Yanli Zhang**, San Jose, CA (US); **Yao-Sheng Lee**, Tampa, FL (US)

(73) Assignee: **SANDISK TECHNOLOGIES LLC**, Addison, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/624,006**

(22) Filed: **Jun. 15, 2017**

(65) **Prior Publication Data**

US 2017/0352669 A1 Dec. 7, 2017

Related U.S. Application Data

(63) Continuation-in-part of application No. 15/223,729, filed on Jul. 29, 2016, now Pat. No. 9,984,963, which
(Continued)

(51) **Int. Cl.**
H01L 27/30 (2006.01)
H01L 27/148 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 27/1157*** (2013.01); ***H01L 23/5226*** (2013.01); ***H01L 23/53266*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 27/11568; H01L 27/11565; H01L 29/7926
See application file for complete search history.

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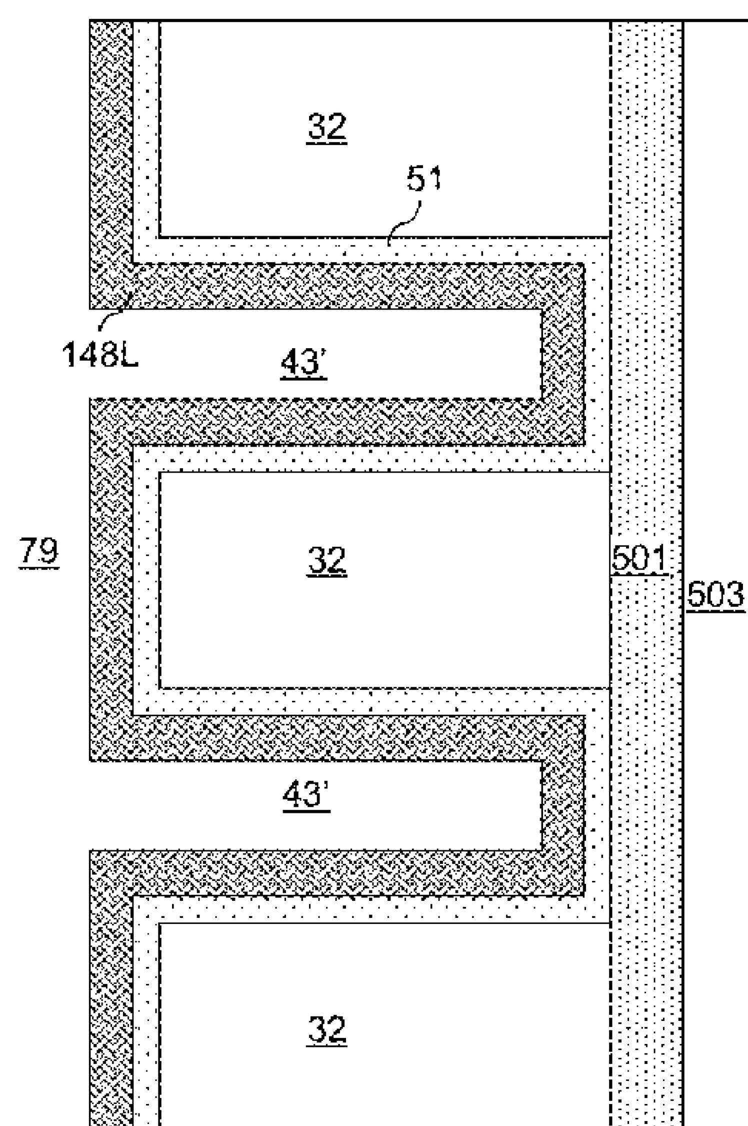
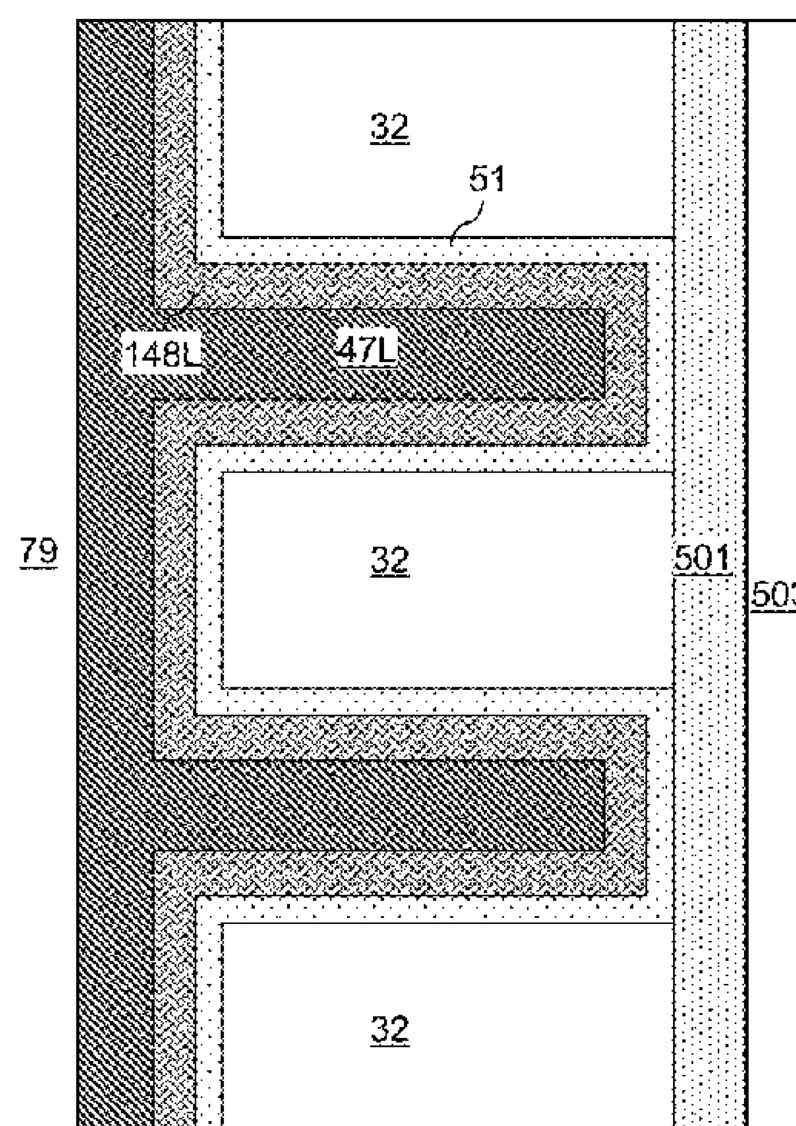
Primary Examiner — Matthew L Reames
Assistant Examiner — John A Bodnar
(74) *Attorney, Agent, or Firm* — The Marbury Law Group, PLLC

(57) **ABSTRACT**

A memory stack structure including a memory film and a vertical semiconductor channel can be formed within each memory opening that extends through a stack including an alternating plurality of insulating layers and sacrificial material layers. After formation of backside recesses through removal of the sacrificial material layers selective to the insulating layers, a backside blocking dielectric layer may be formed in the backside recesses and sidewalls of the memory stack structures. A metallic barrier material portion can be formed in each backside recess. A metallic material portion is formed on the metallic barrier material portion. Subsequently, a metal portion comprising a material selected from cobalt and ruthenium is formed directly on a sidewall of the metallic barrier material portion and a sidewall of the
(Continued)





metallic material portion and an overlying insulating surface and an underlying insulating surface.

7 Claims, 44 Drawing Sheets

Related U.S. Application Data

is a continuation-in-part of application No. 14/613, 956, filed on Feb. 4, 2015, now Pat. No. 10,128,261.

(60) Provisional application No. 62/478,272, filed on Mar. 29, 2017, provisional application No. 62/300,221, filed on Feb. 26, 2016.

(51) **Int. Cl.**

H01L 51/44	(2006.01)
H01L 51/42	(2006.01)
H04N 5/372	(2011.01)
H01L 27/1157	(2017.01)
H01L 27/11524	(2017.01)
H01L 27/11556	(2017.01)
H01L 23/532	(2006.01)
H01L 27/11573	(2017.01)
H01L 23/522	(2006.01)
H01L 29/66	(2006.01)
H01L 29/788	(2006.01)
H01L 29/792	(2006.01)
H01L 27/11526	(2017.01)
H01L 27/11548	(2017.01)
H01L 27/11575	(2017.01)
H01L 27/11582	(2017.01)
H01L 29/49	(2006.01)
H01L 21/768	(2006.01)

(52) **U.S. Cl.**

CPC .. ***H01L 27/11524*** (2013.01); ***H01L 27/11526*** (2013.01); ***H01L 27/11548*** (2013.01); ***H01L 27/11556*** (2013.01); ***H01L 27/11573*** (2013.01); ***H01L 27/11575*** (2013.01); ***H01L 27/11582*** (2013.01); ***H01L 29/4958*** (2013.01); ***H01L 29/4966*** (2013.01); ***H01L 29/66825*** (2013.01); ***H01L 29/66833*** (2013.01); ***H01L 29/7889*** (2013.01); ***H01L 29/7926*** (2013.01); *H01L 21/76816* (2013.01); *H01L 21/76877* (2013.01); *H01L 21/76879* (2013.01)

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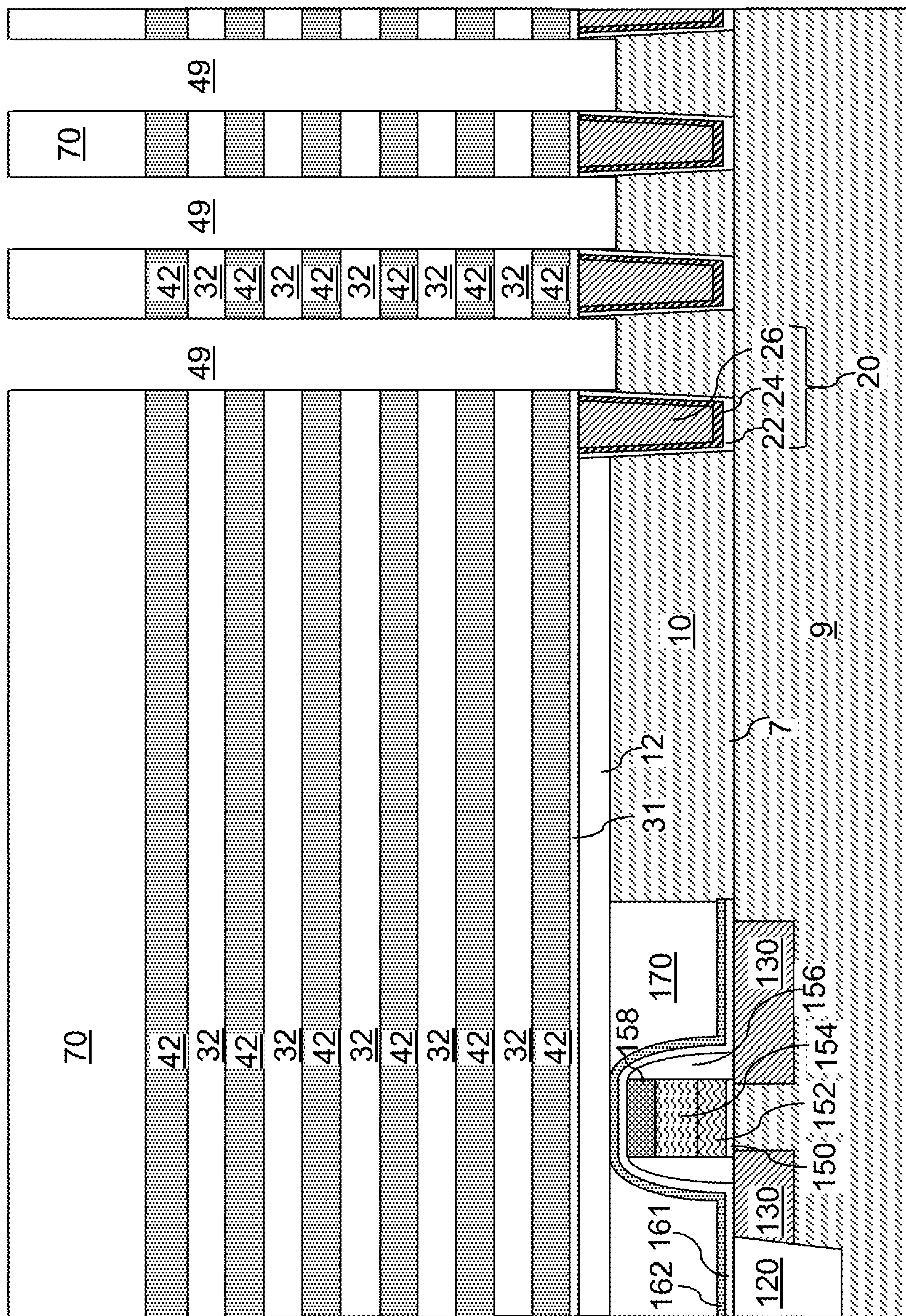

FIG. 1

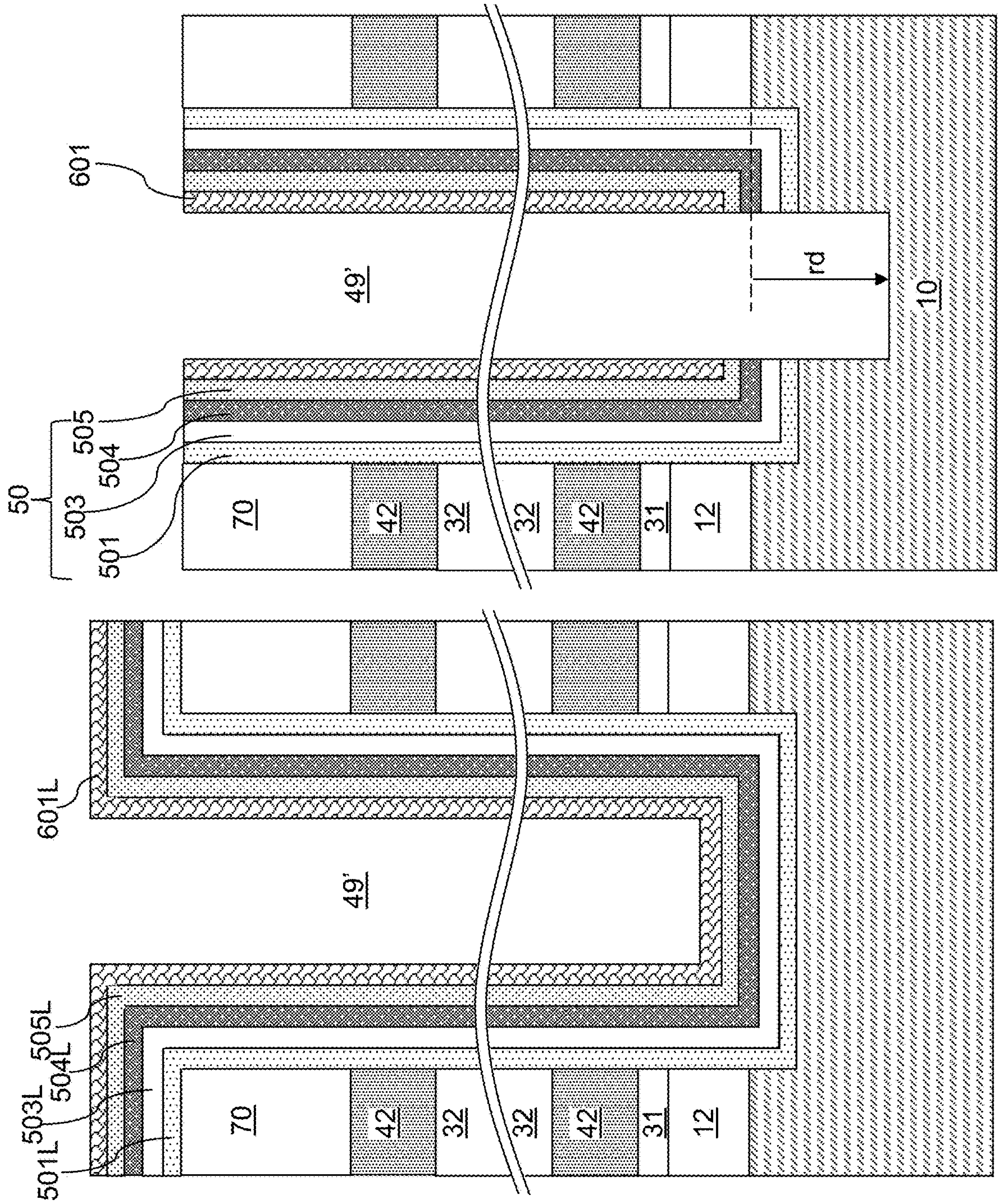

FIG. 2B

FIG. 2A

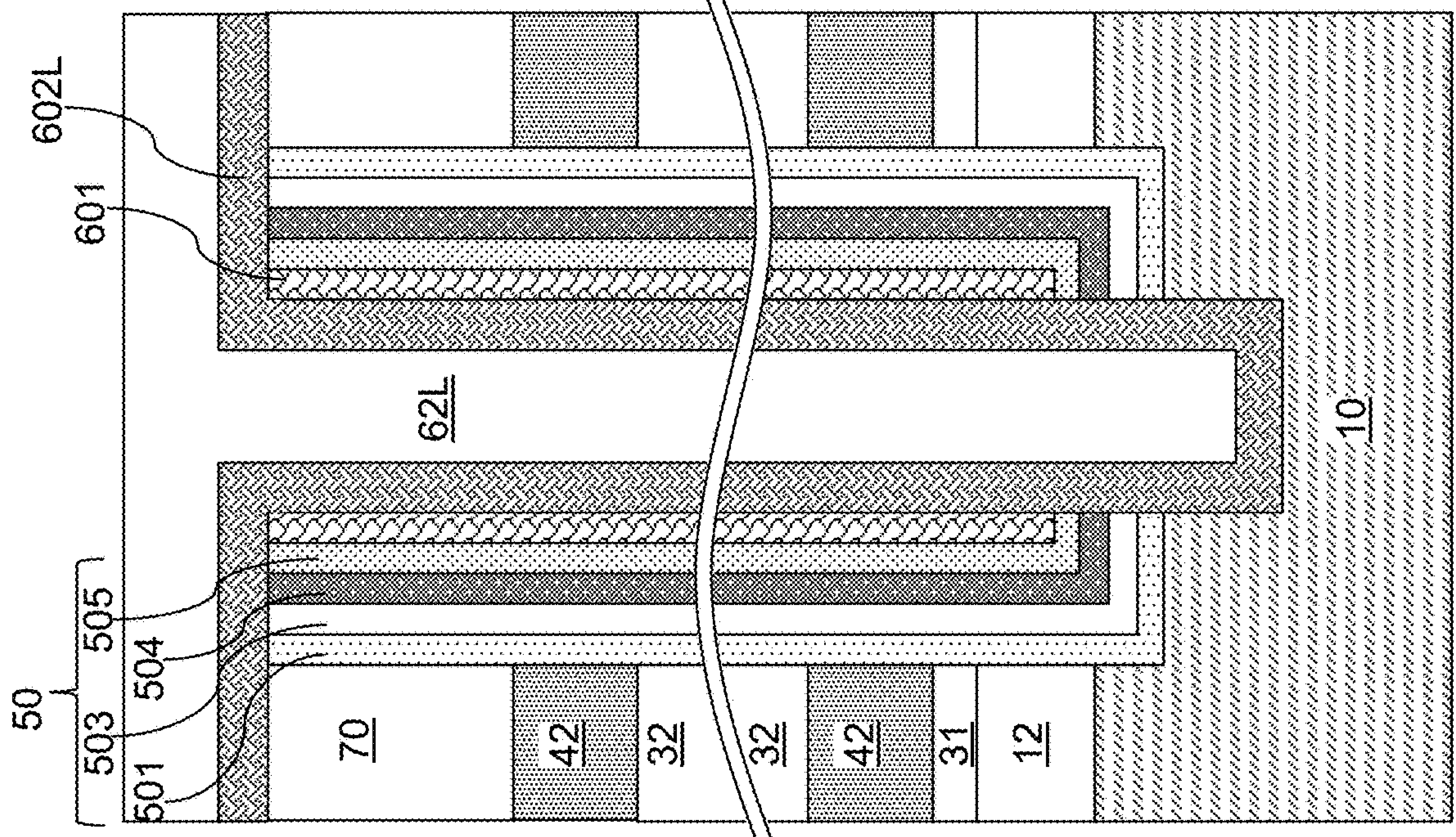

FIG. 2D

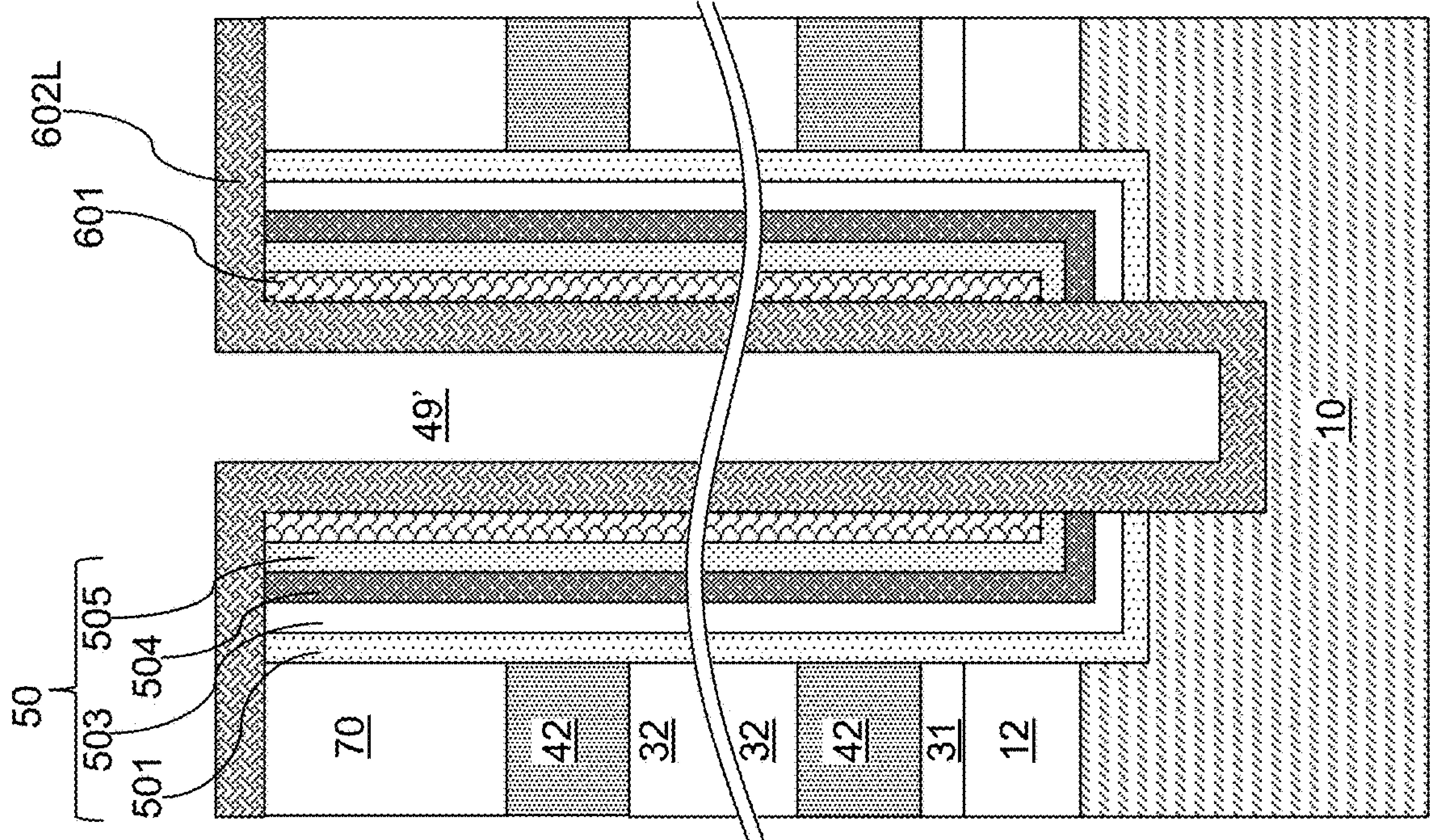

FIG. 2C

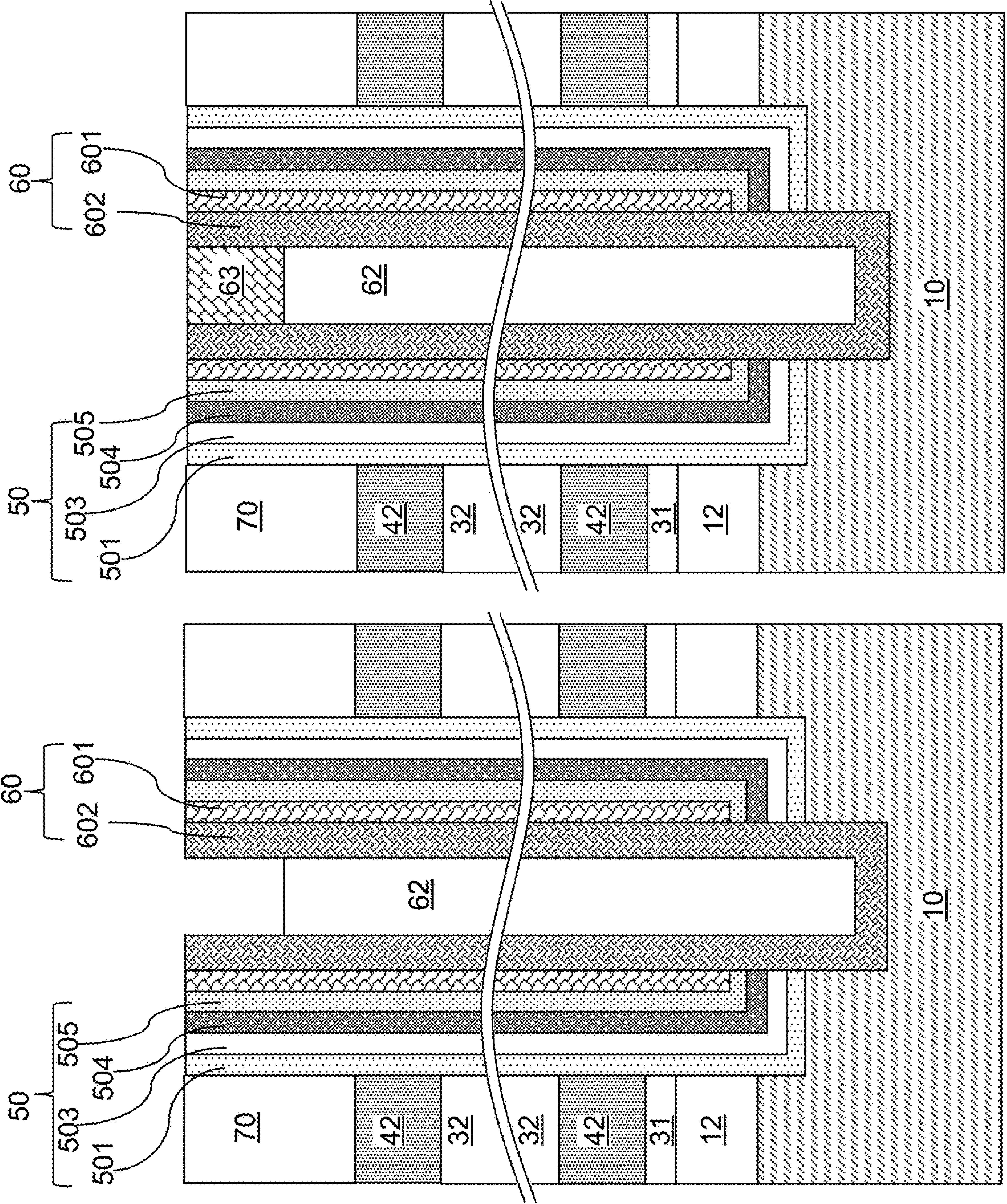

FIG. 2F

FIG. 2E

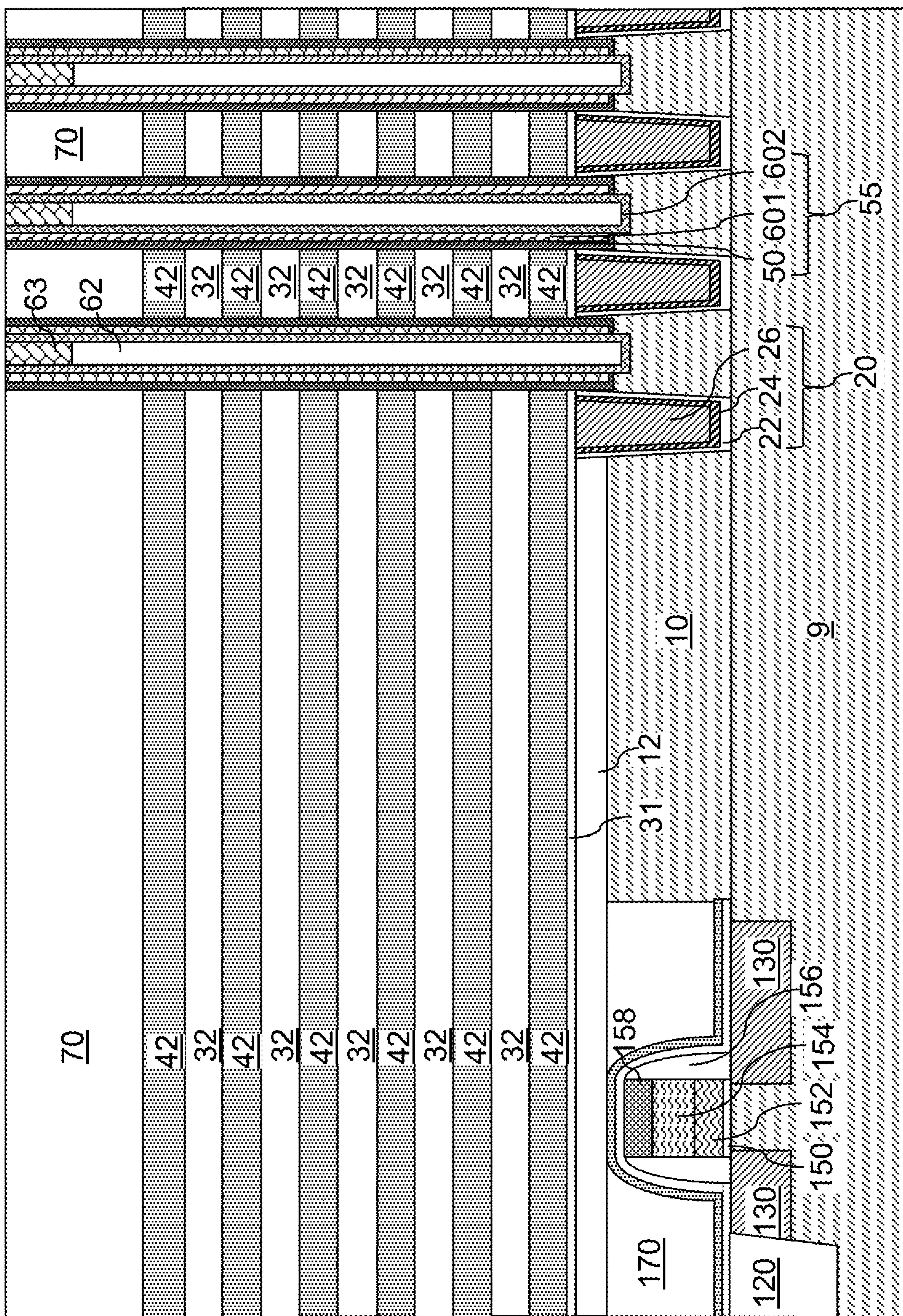

FIG. 3

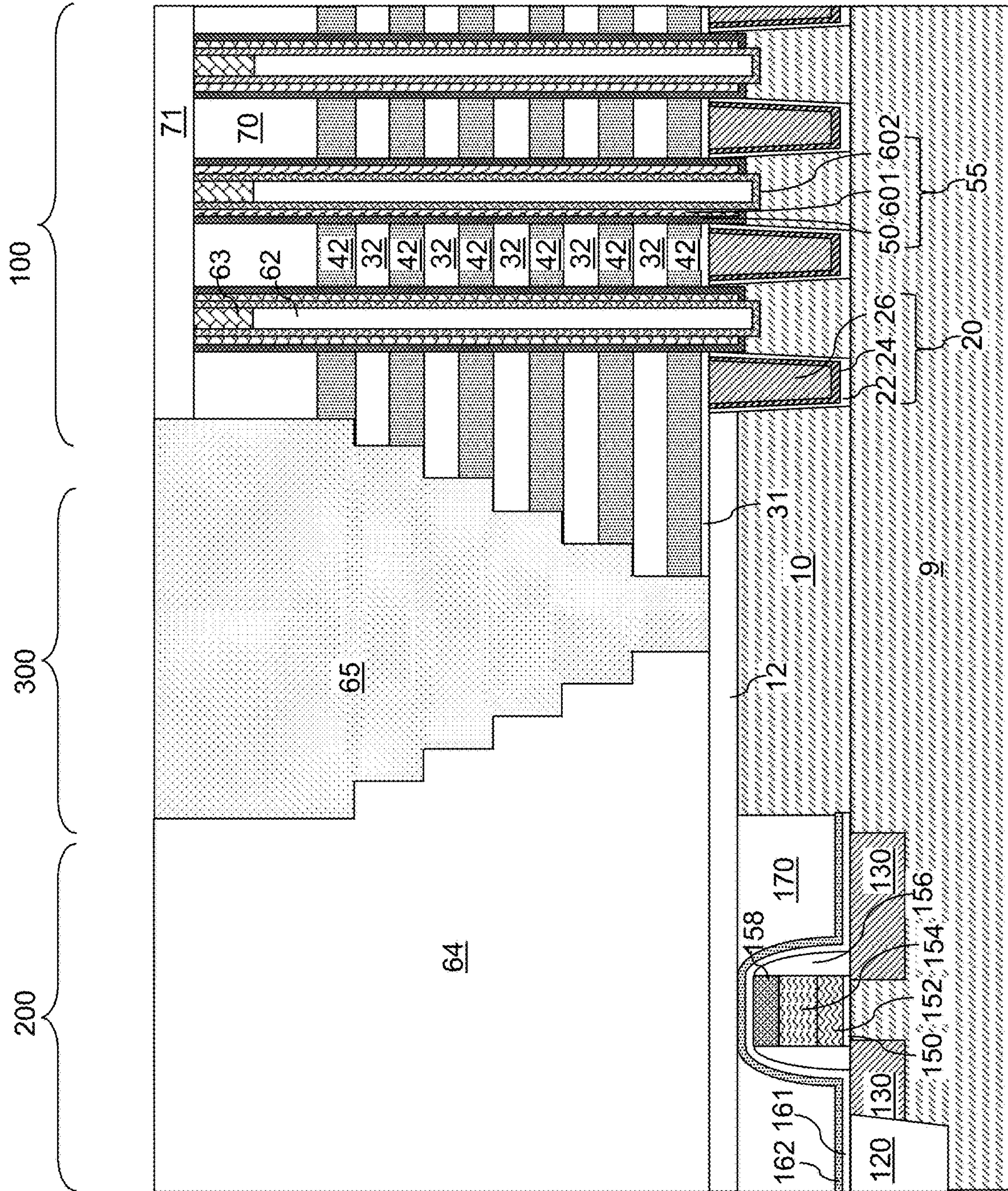

FIG. 4

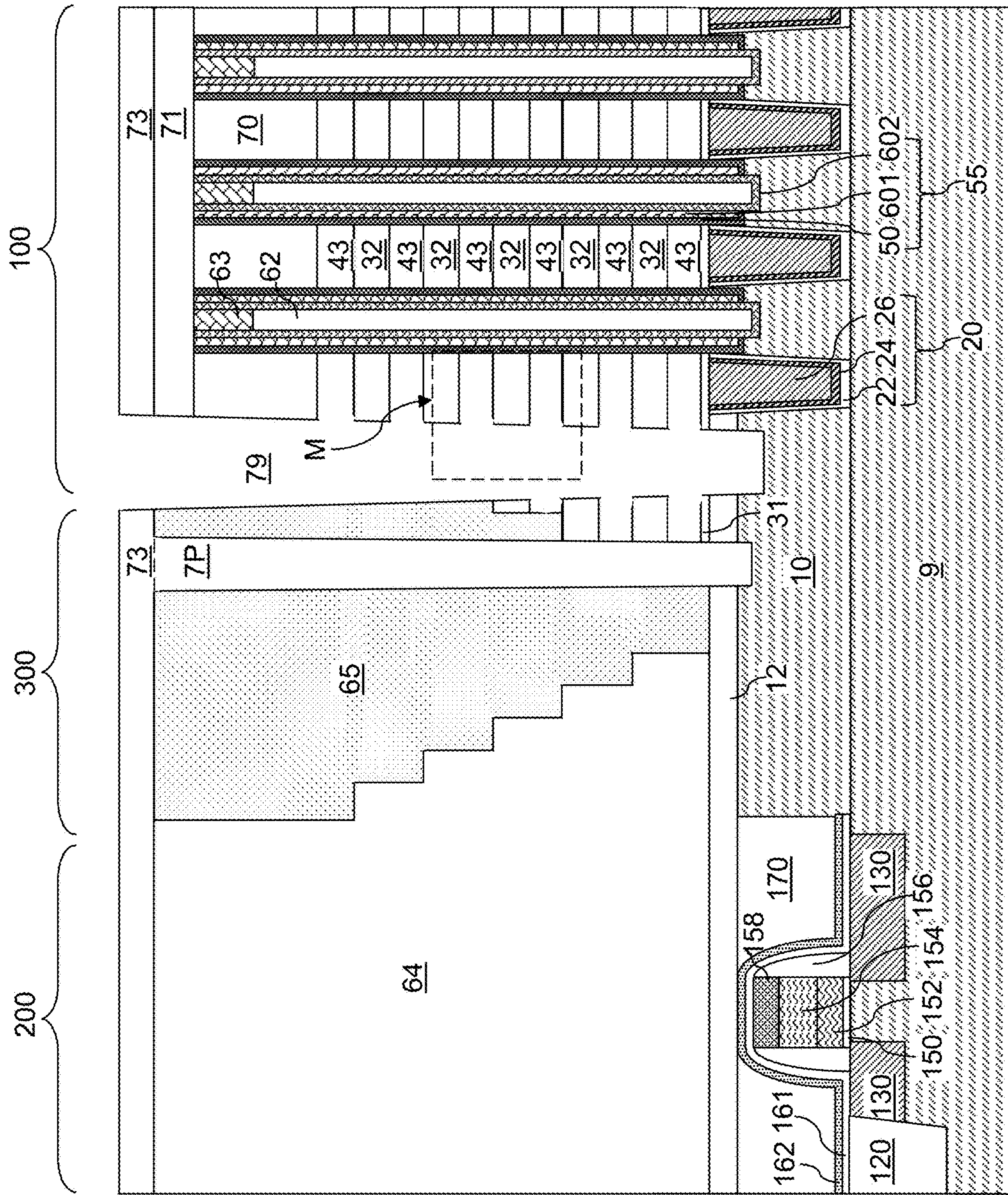

FIG. 5A

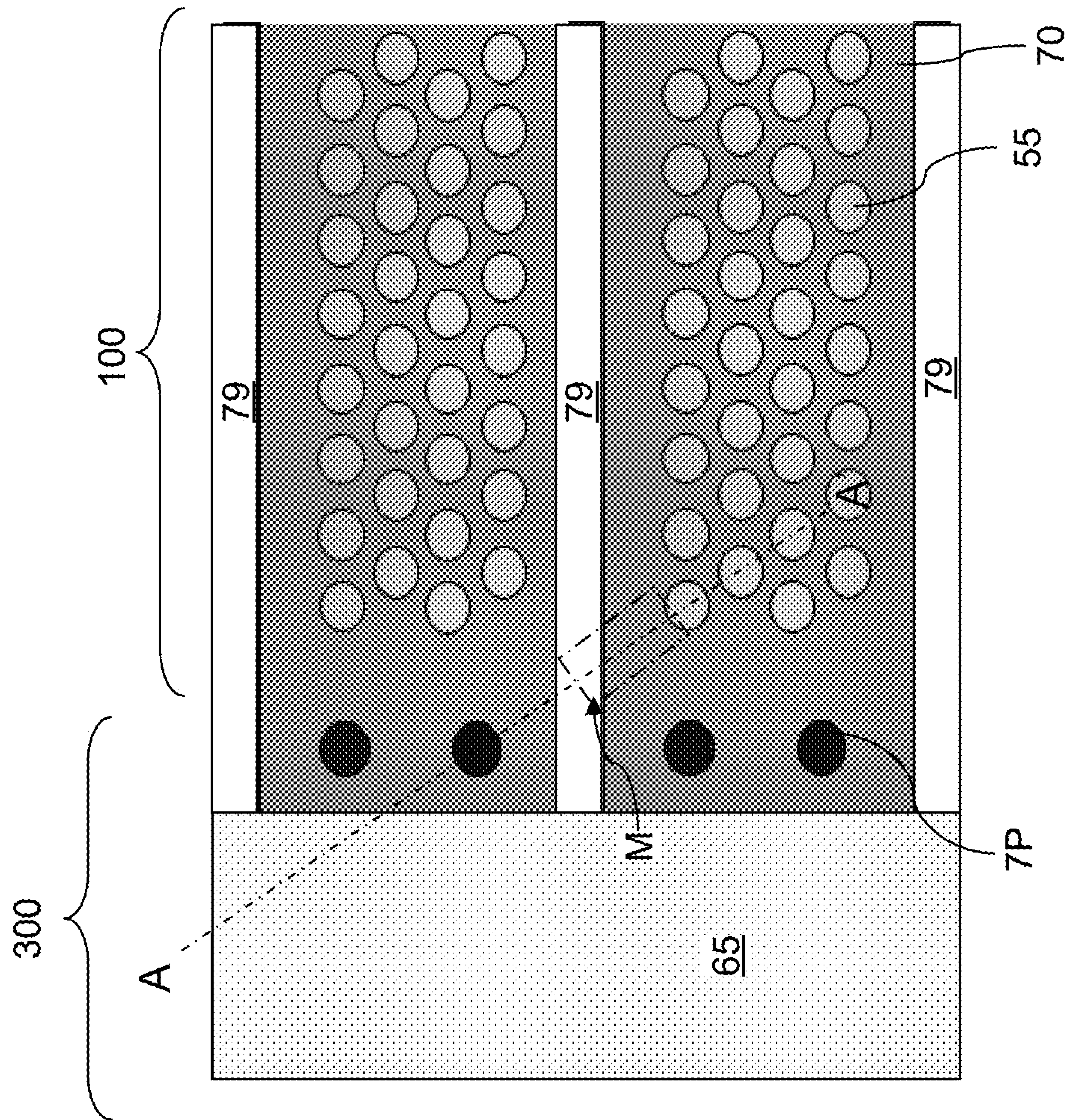

FIG. 5B

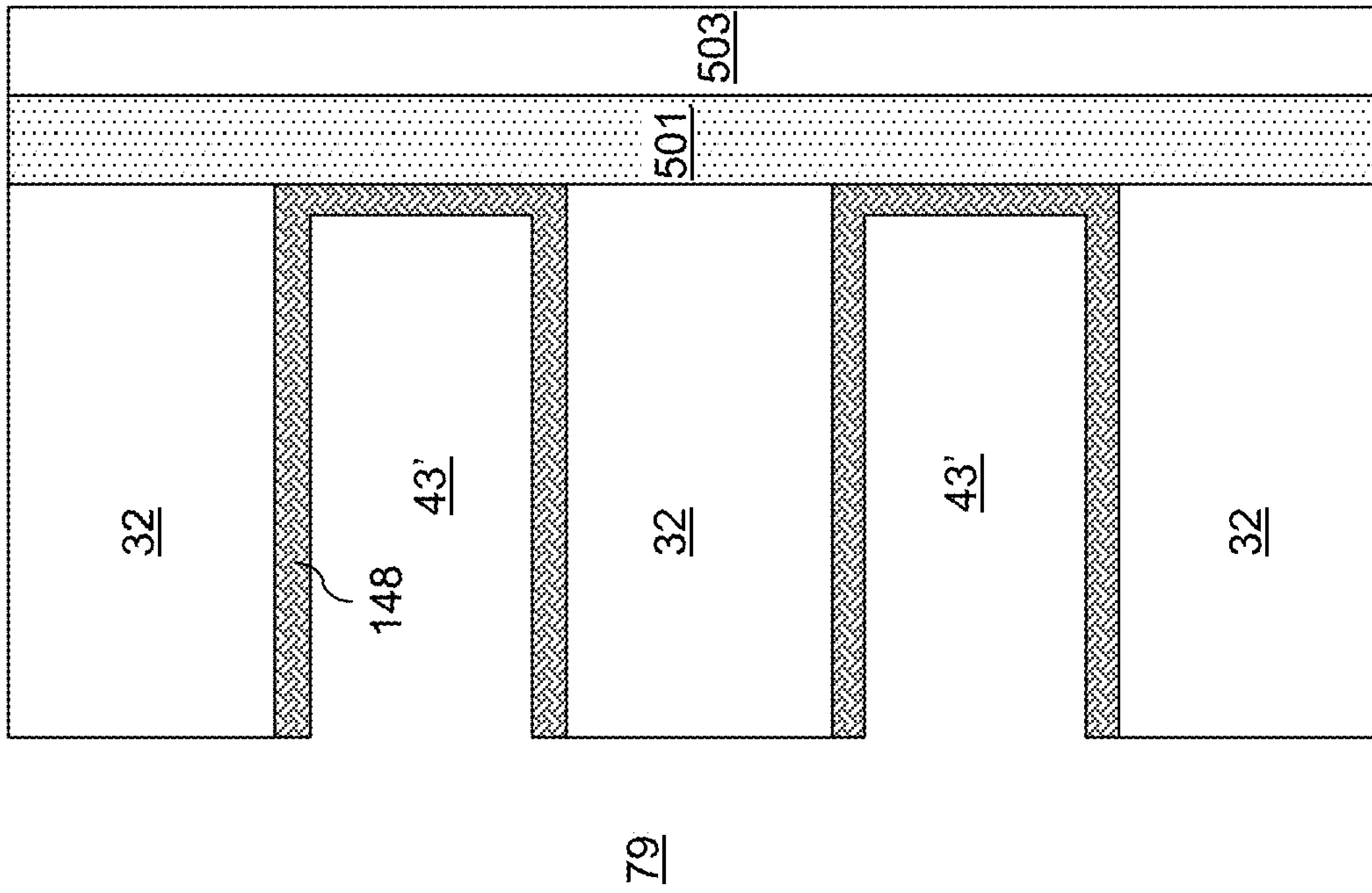

FIG. 6B

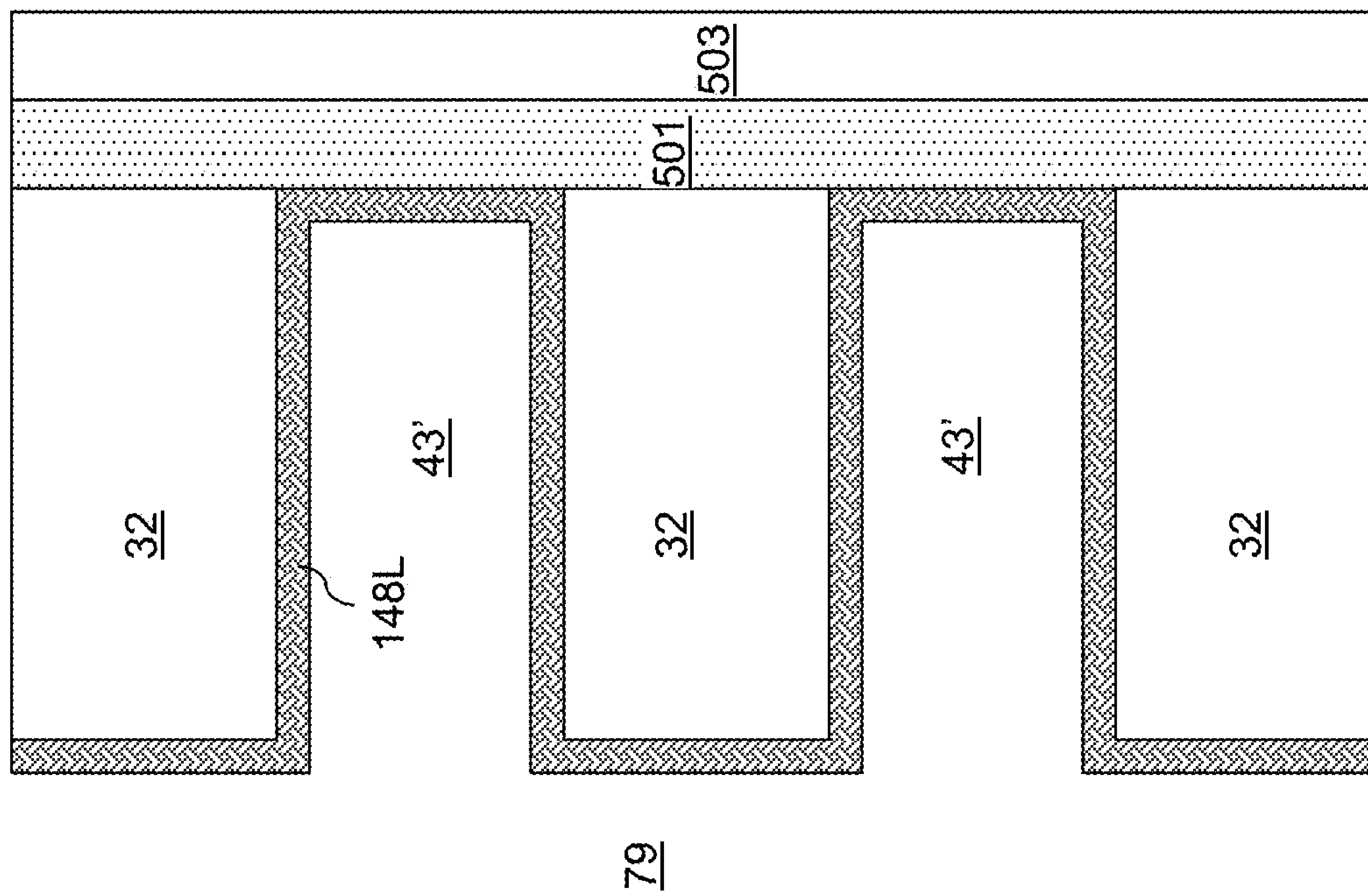

FIG. 6A

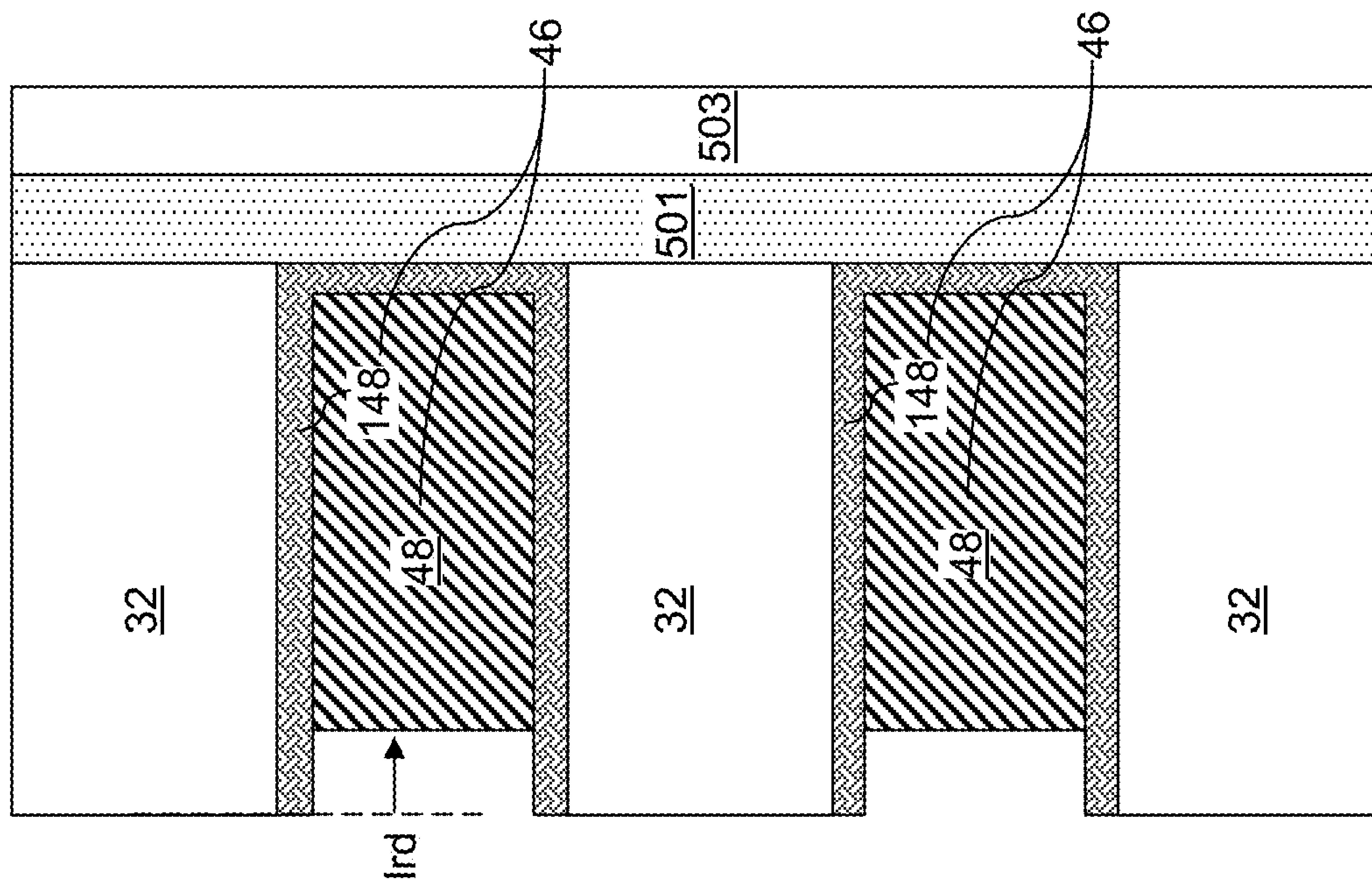

FIG. 6D

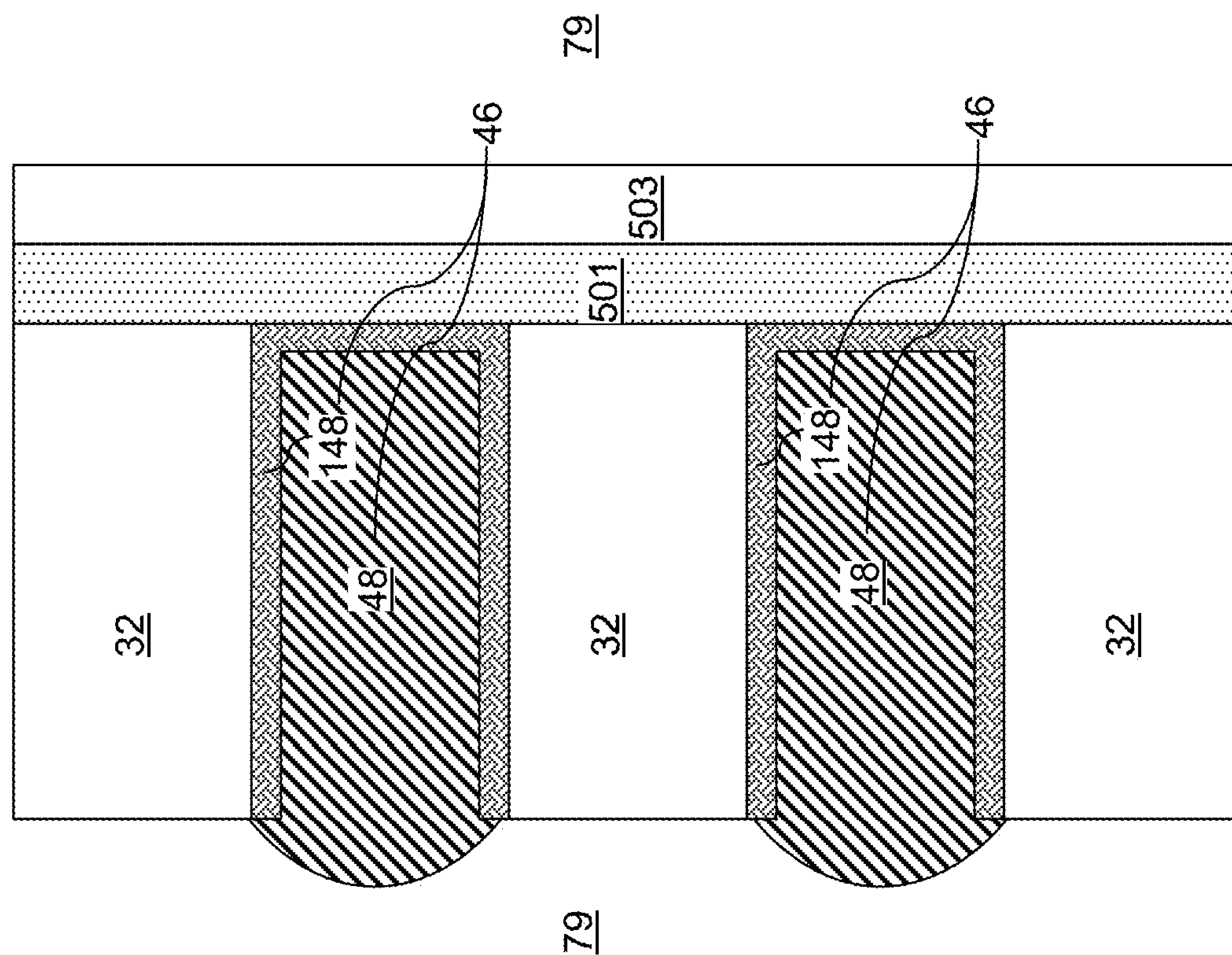

FIG. 6C

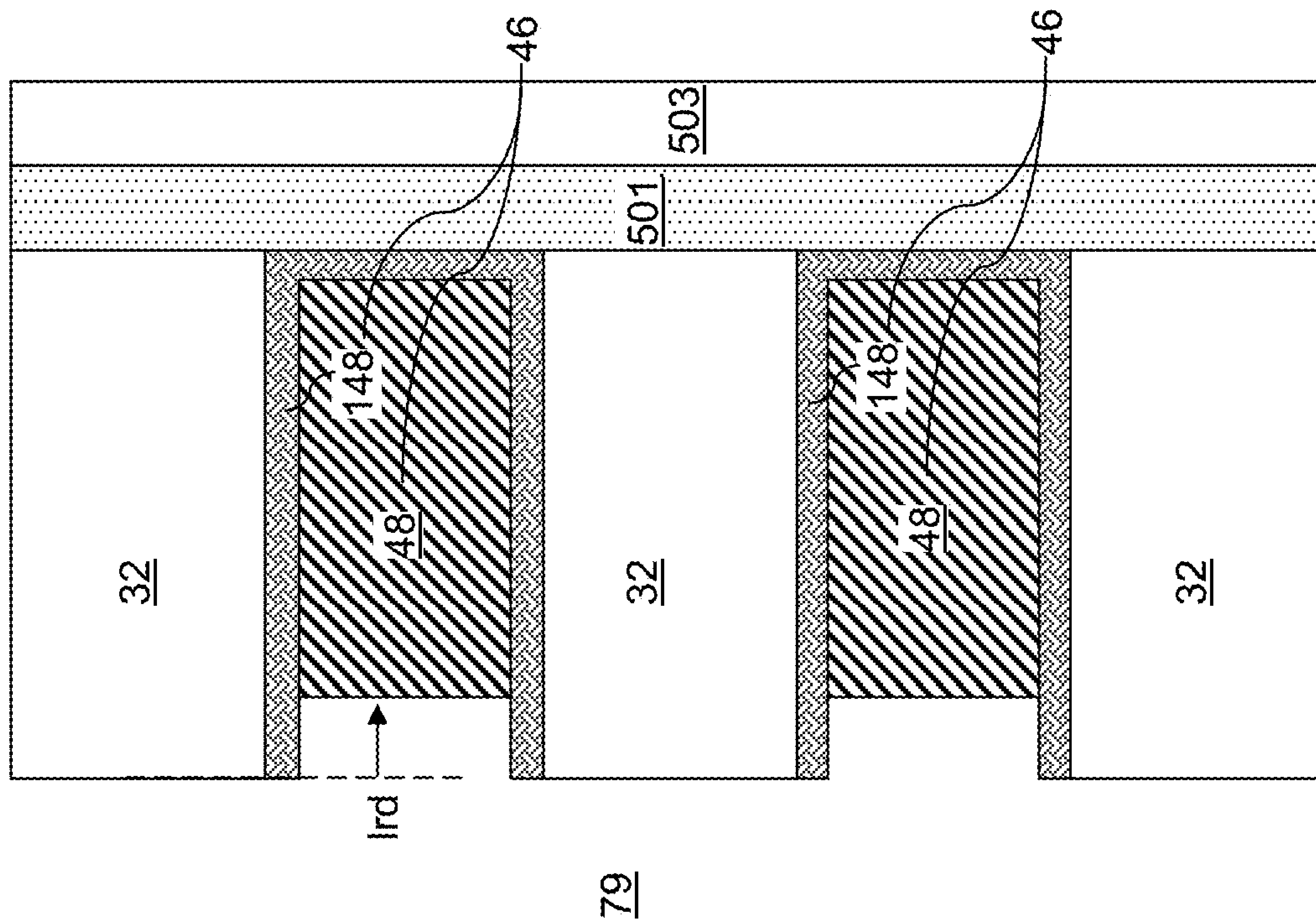

FIG. 7B

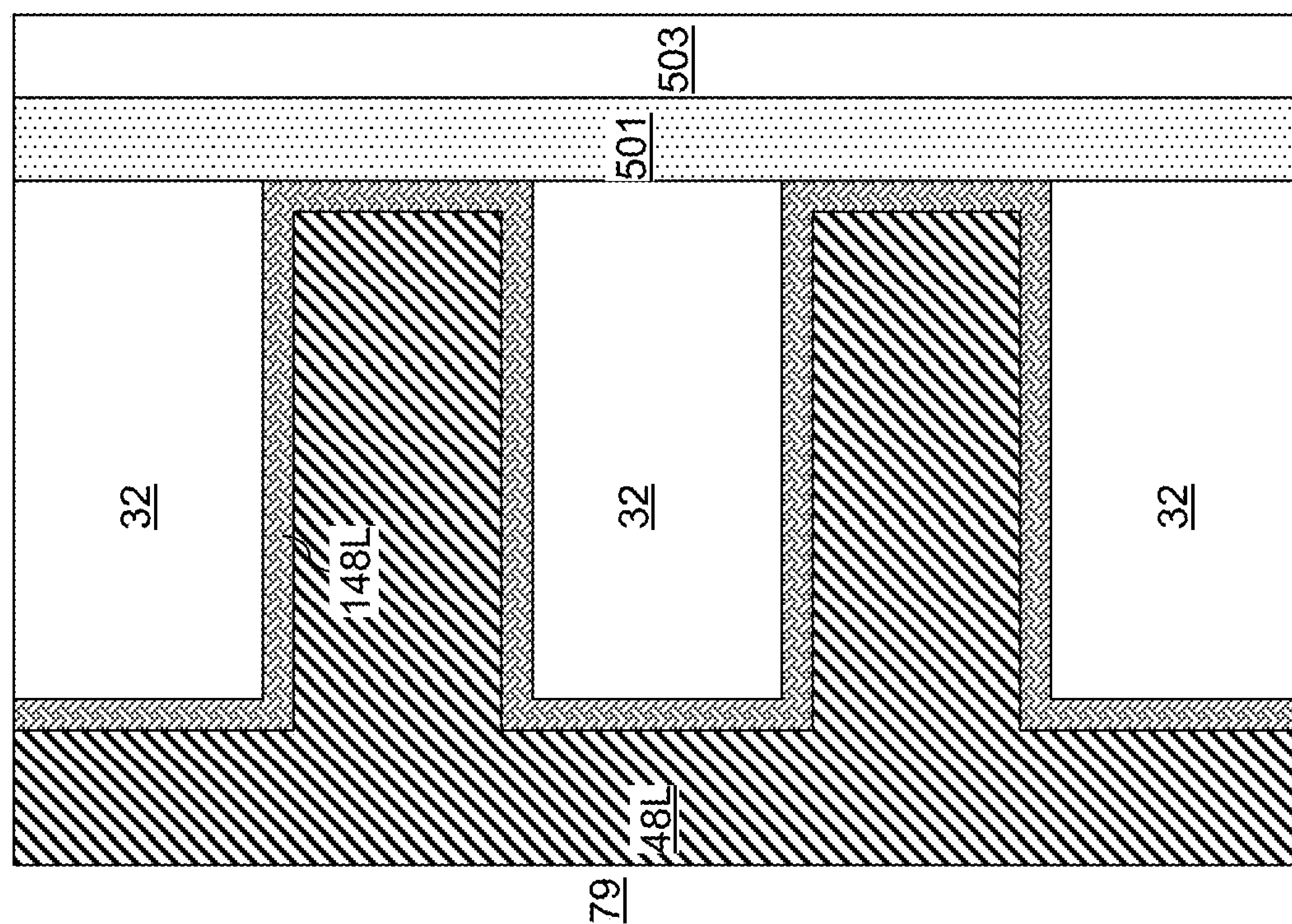

FIG. 7A

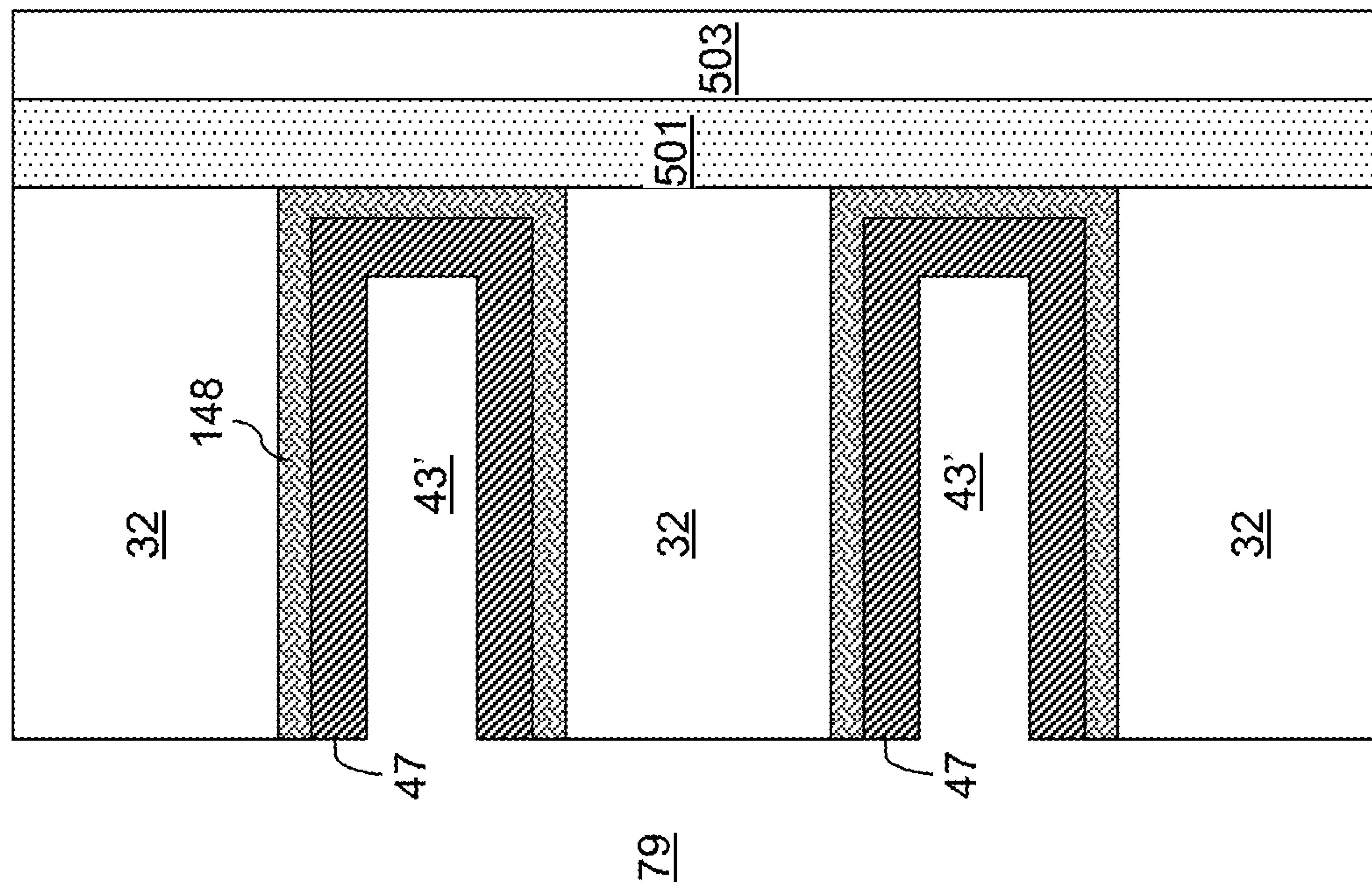

FIG. 8B

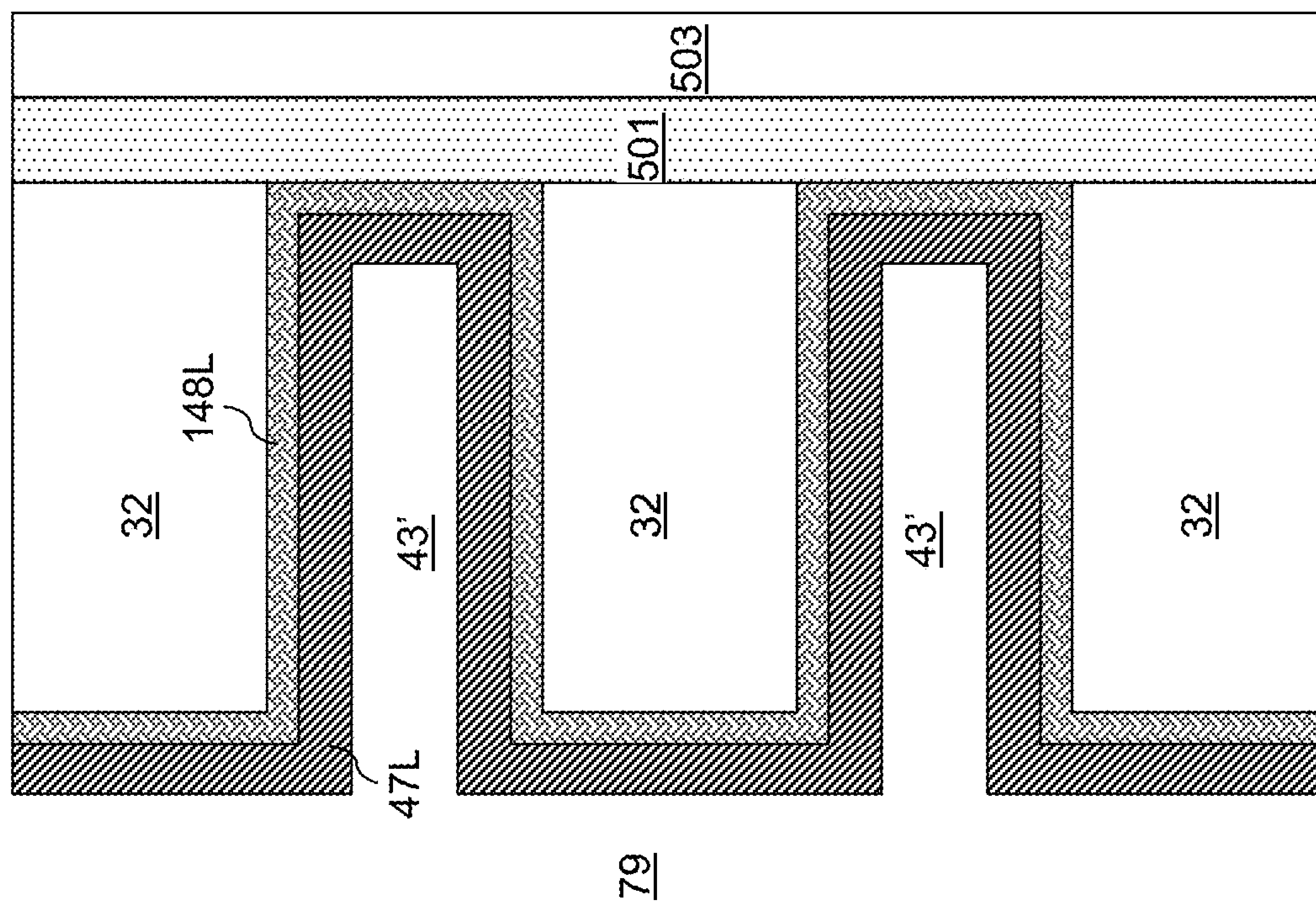

FIG. 8A

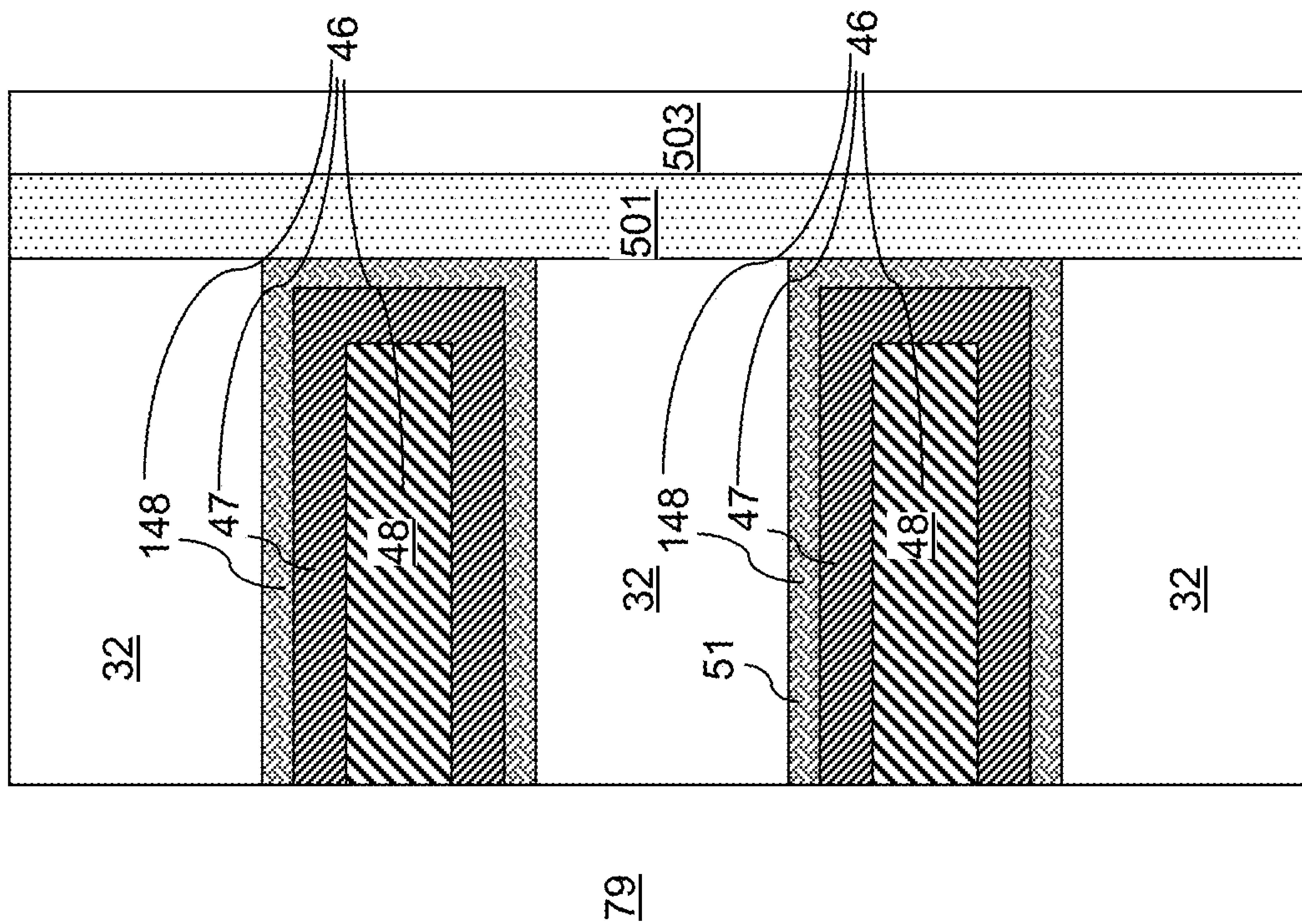

FIG. 8C

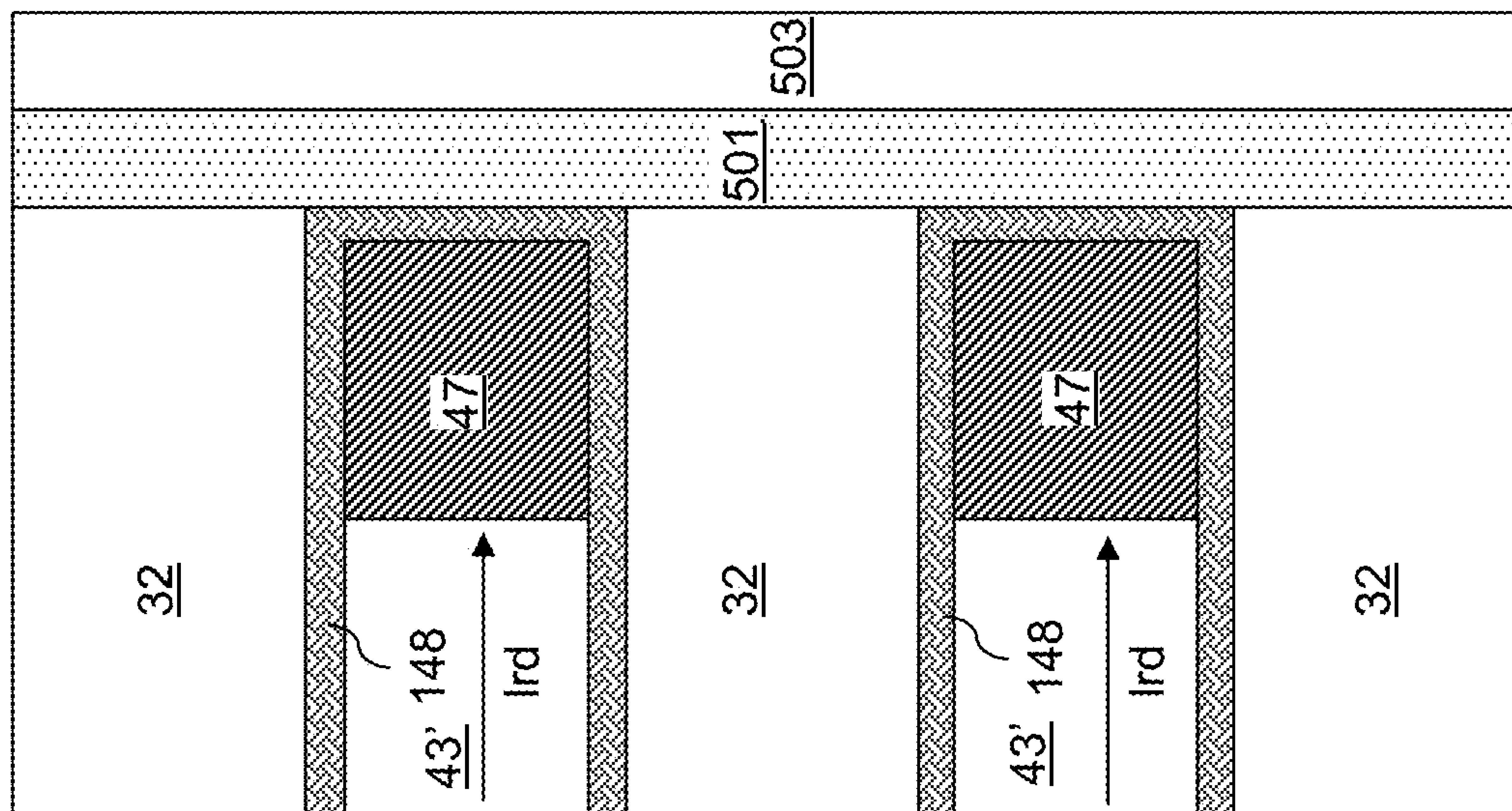

FIG. 9B

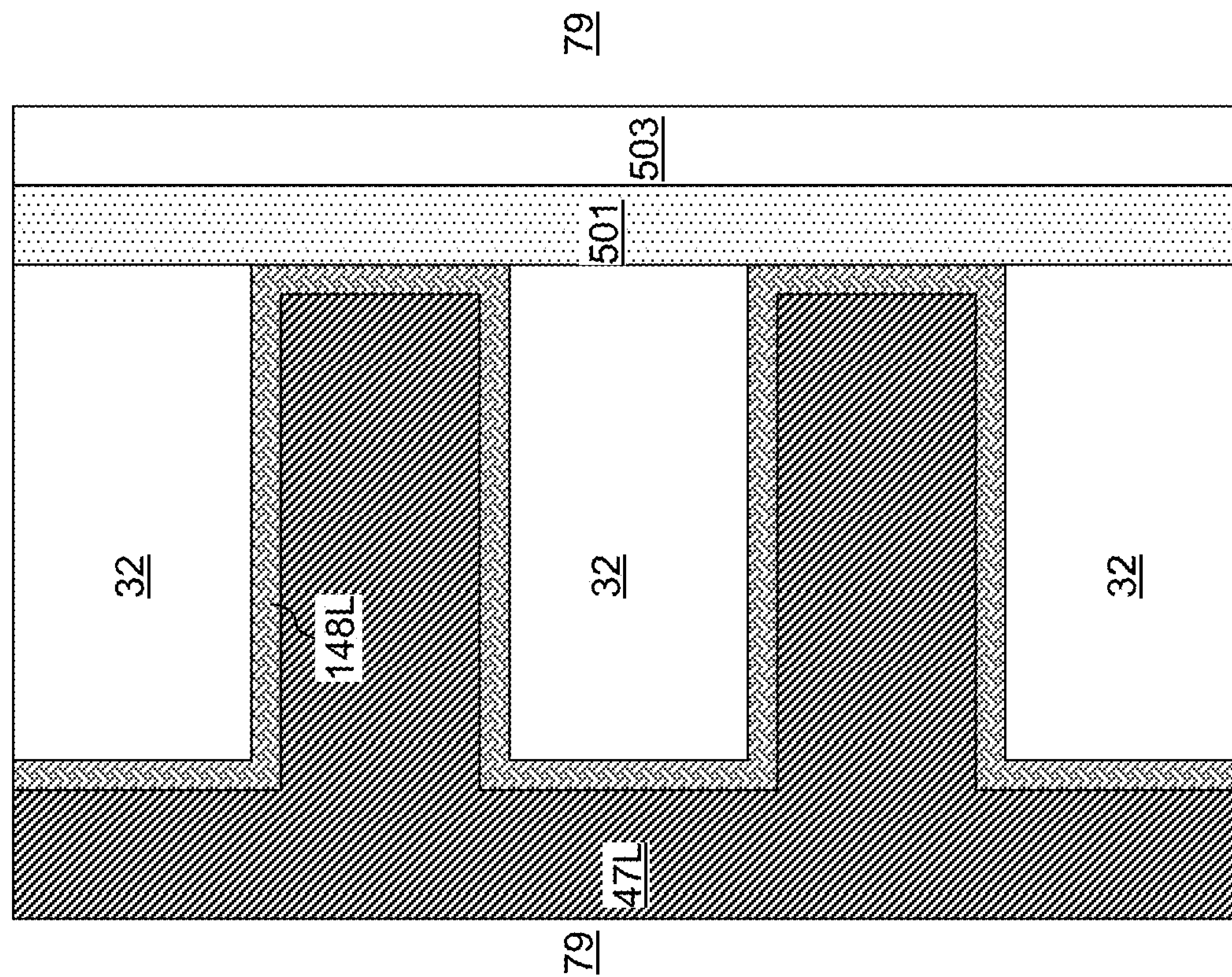

FIG. 9A

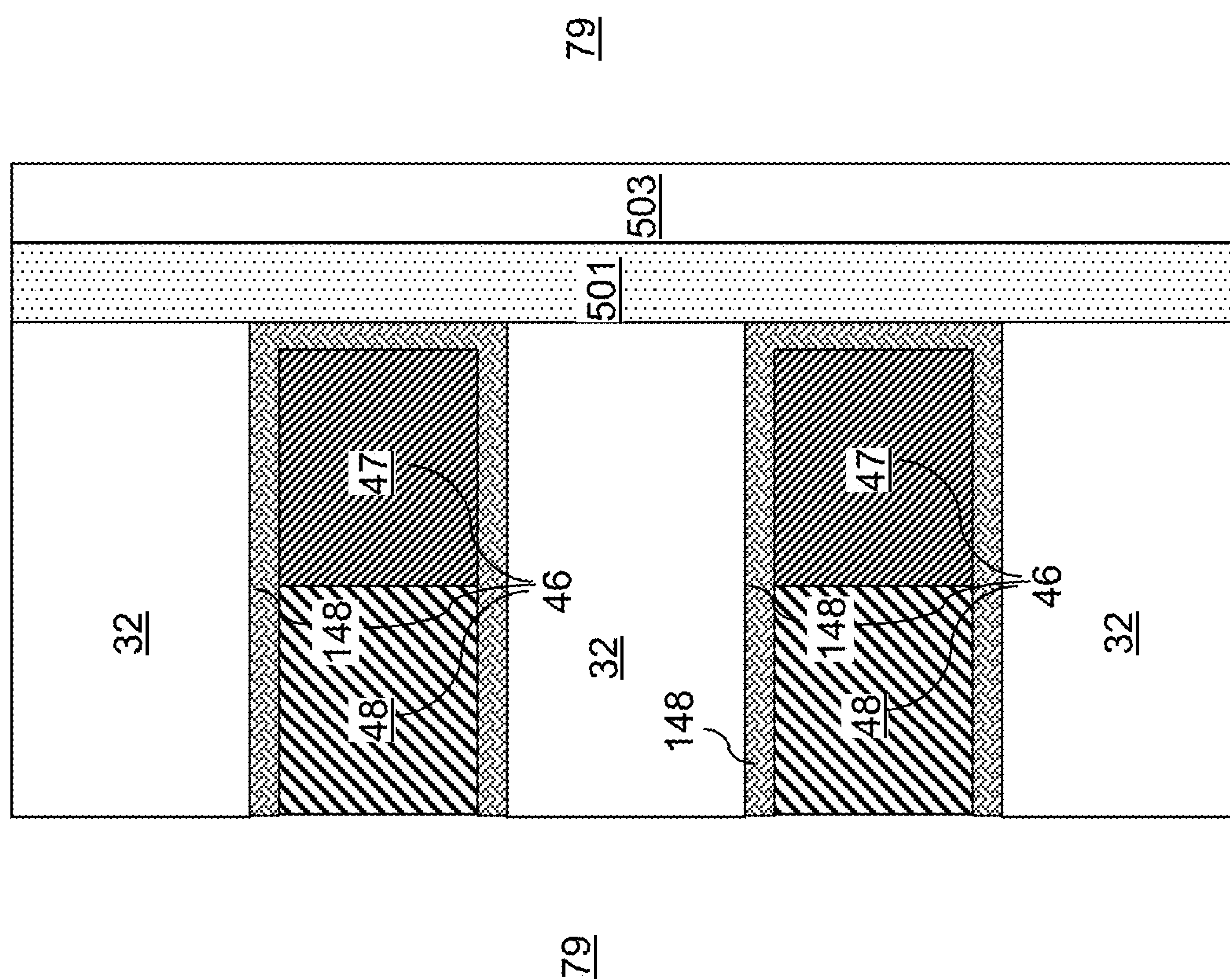

FIG. 9C

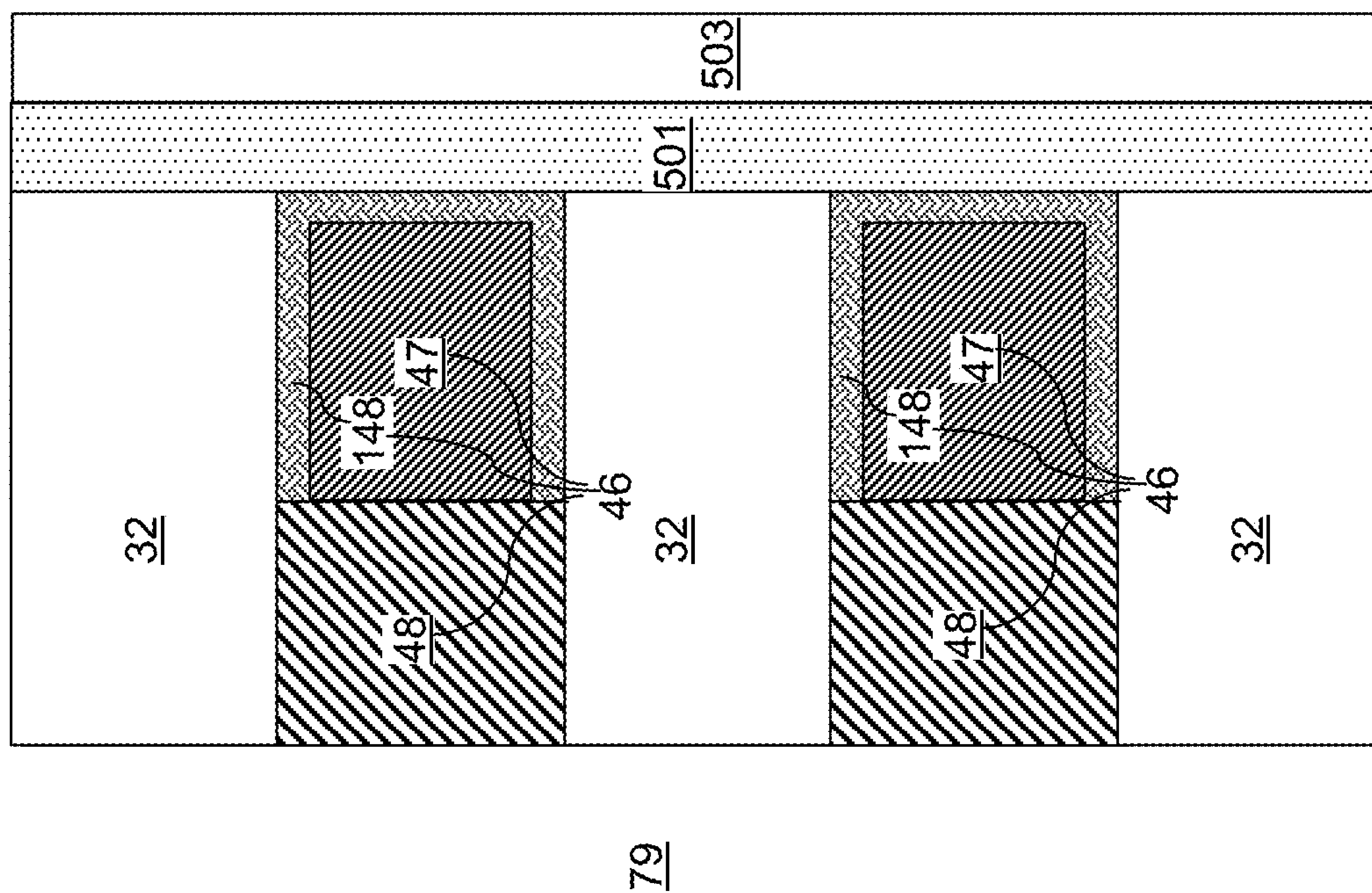

FIG. 10B

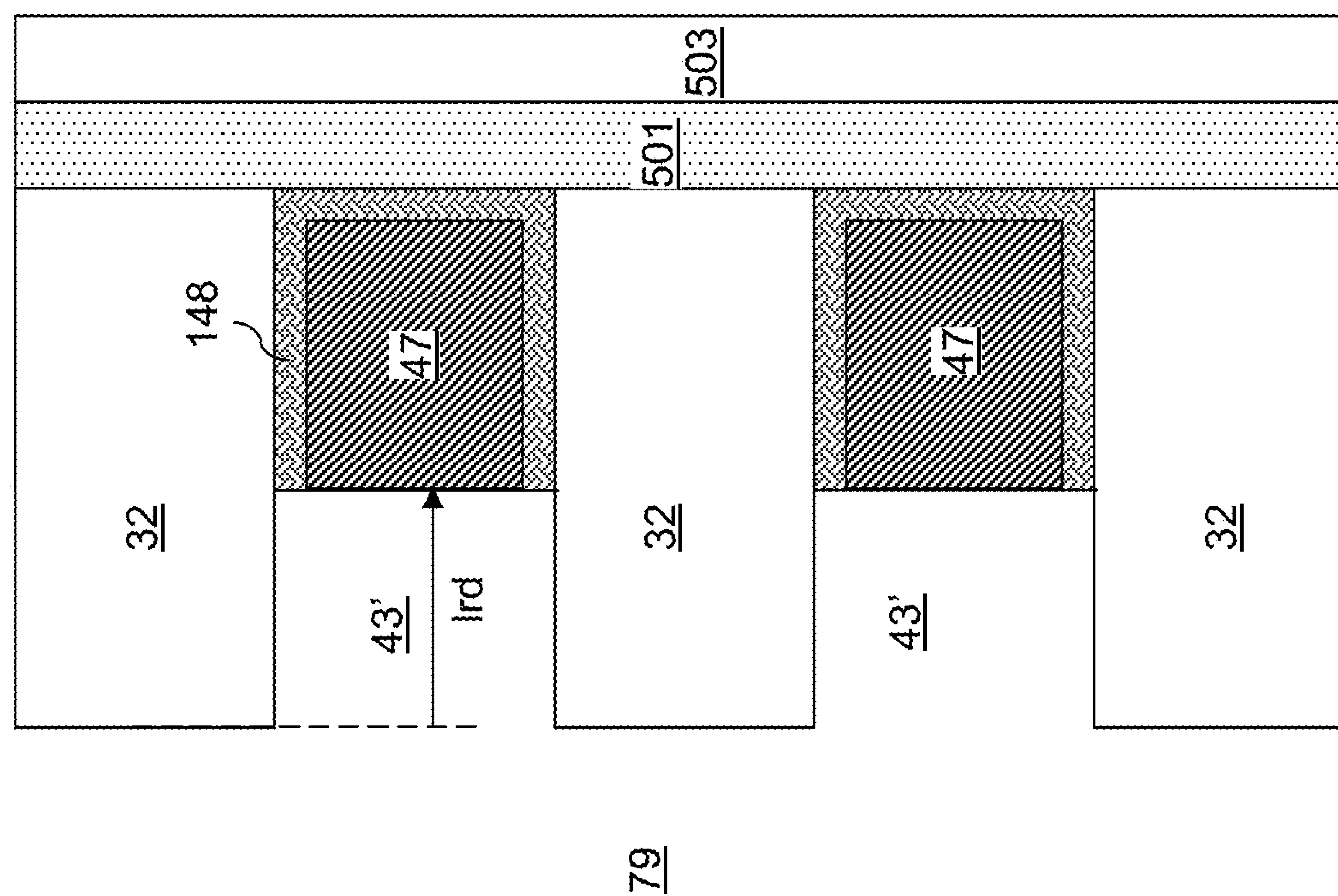

FIG. 10A

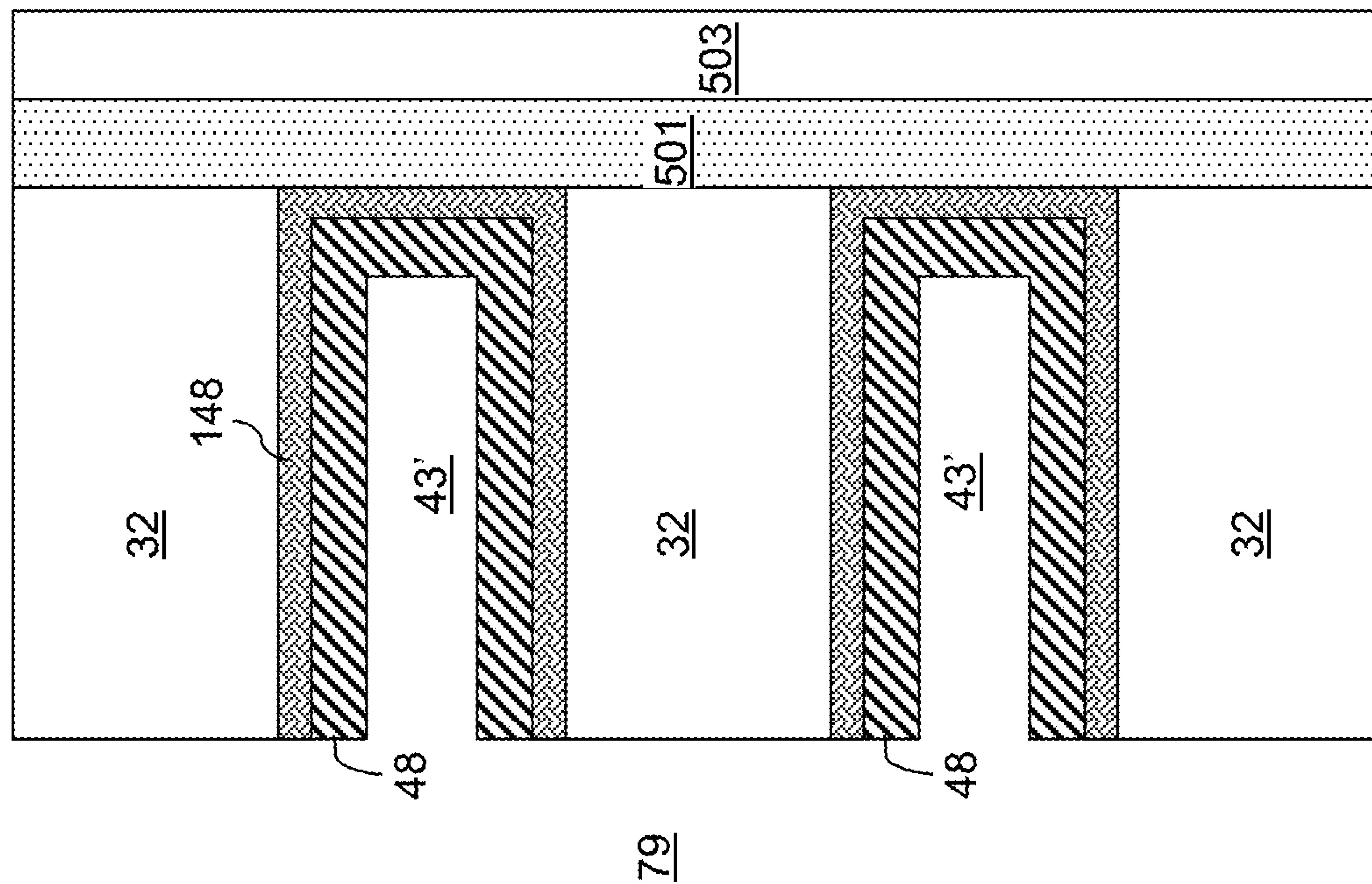

FIG. 11B

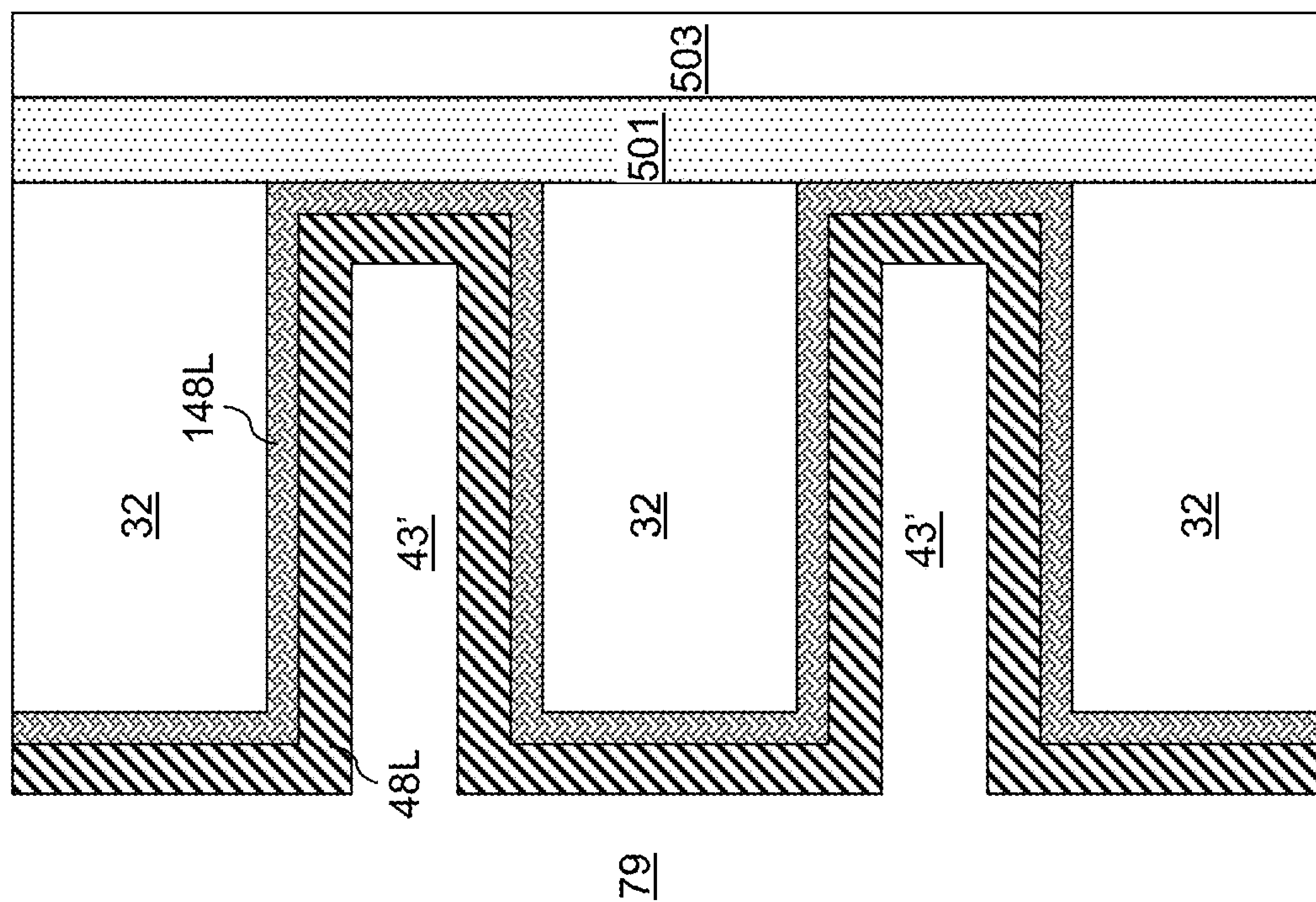

FIG. 11A

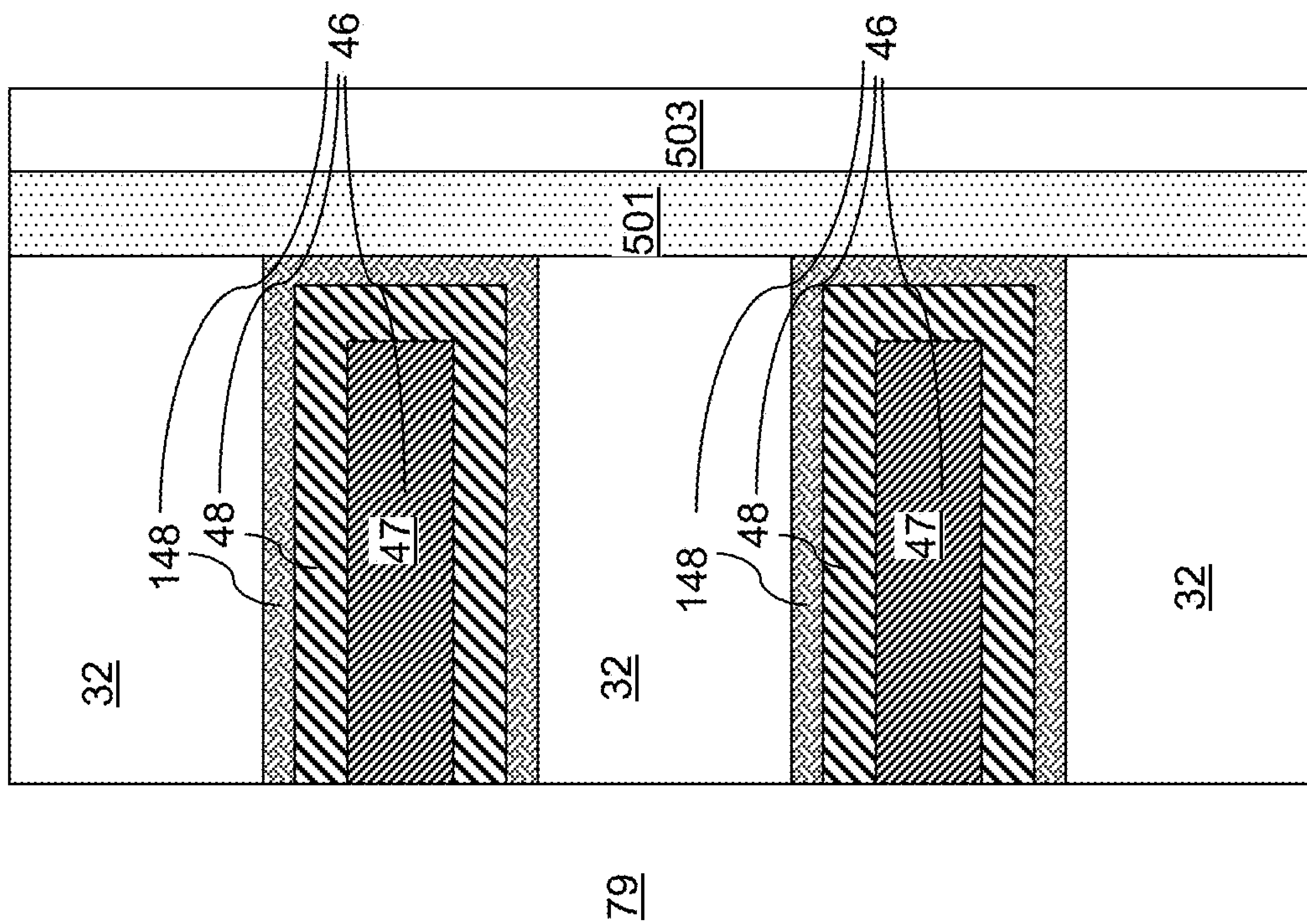

FIG. 11C

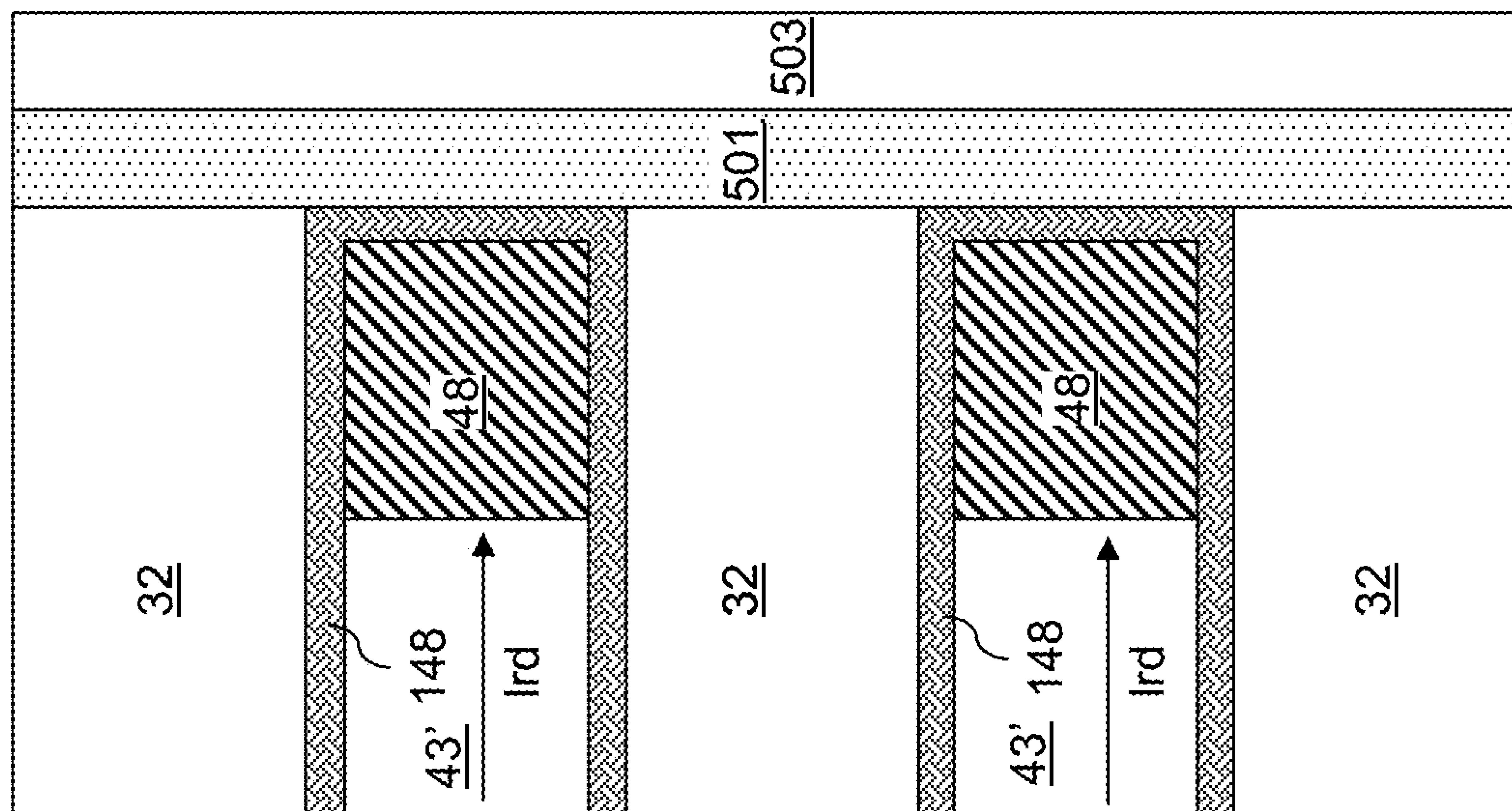

FIG. 12B

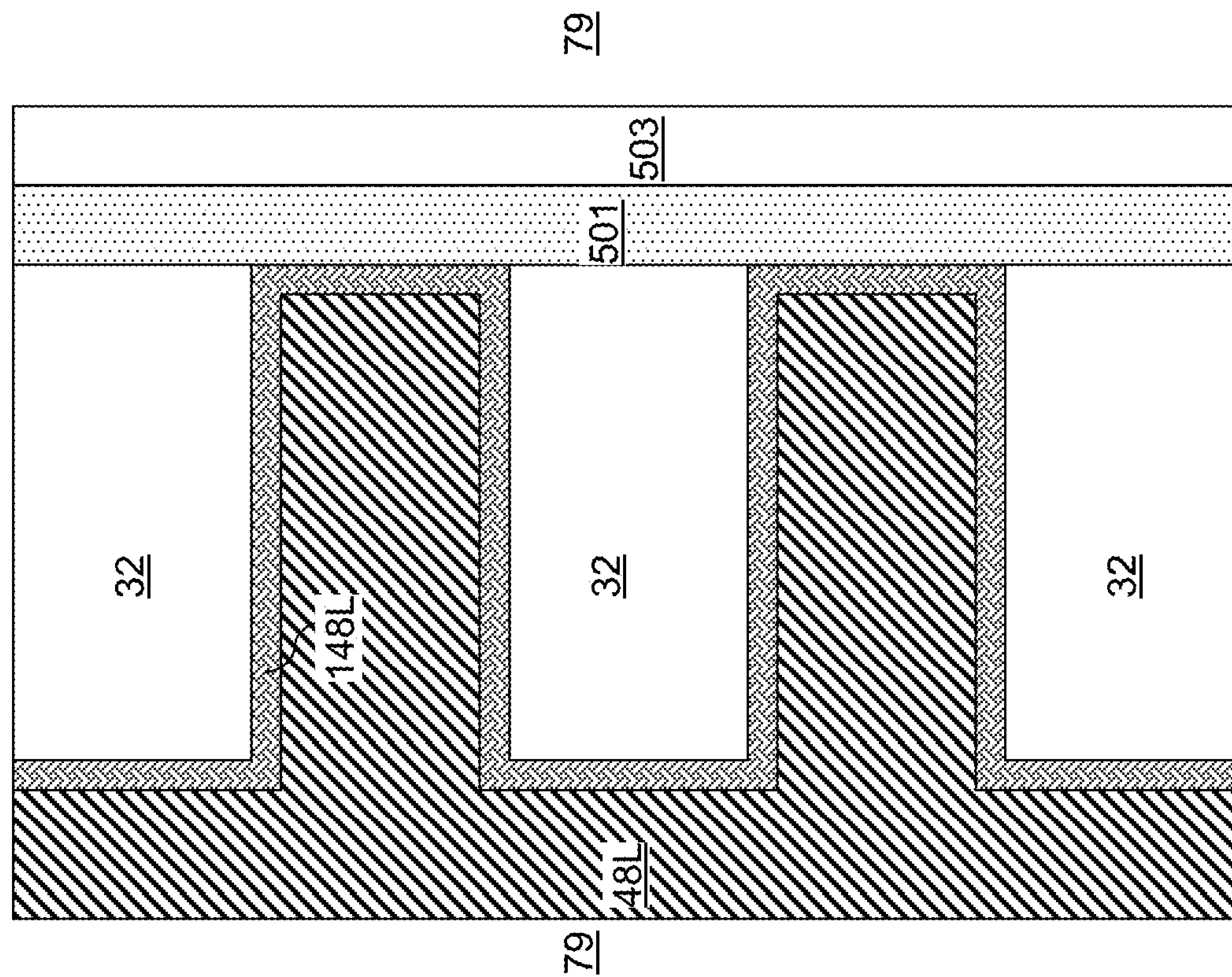

FIG. 12A

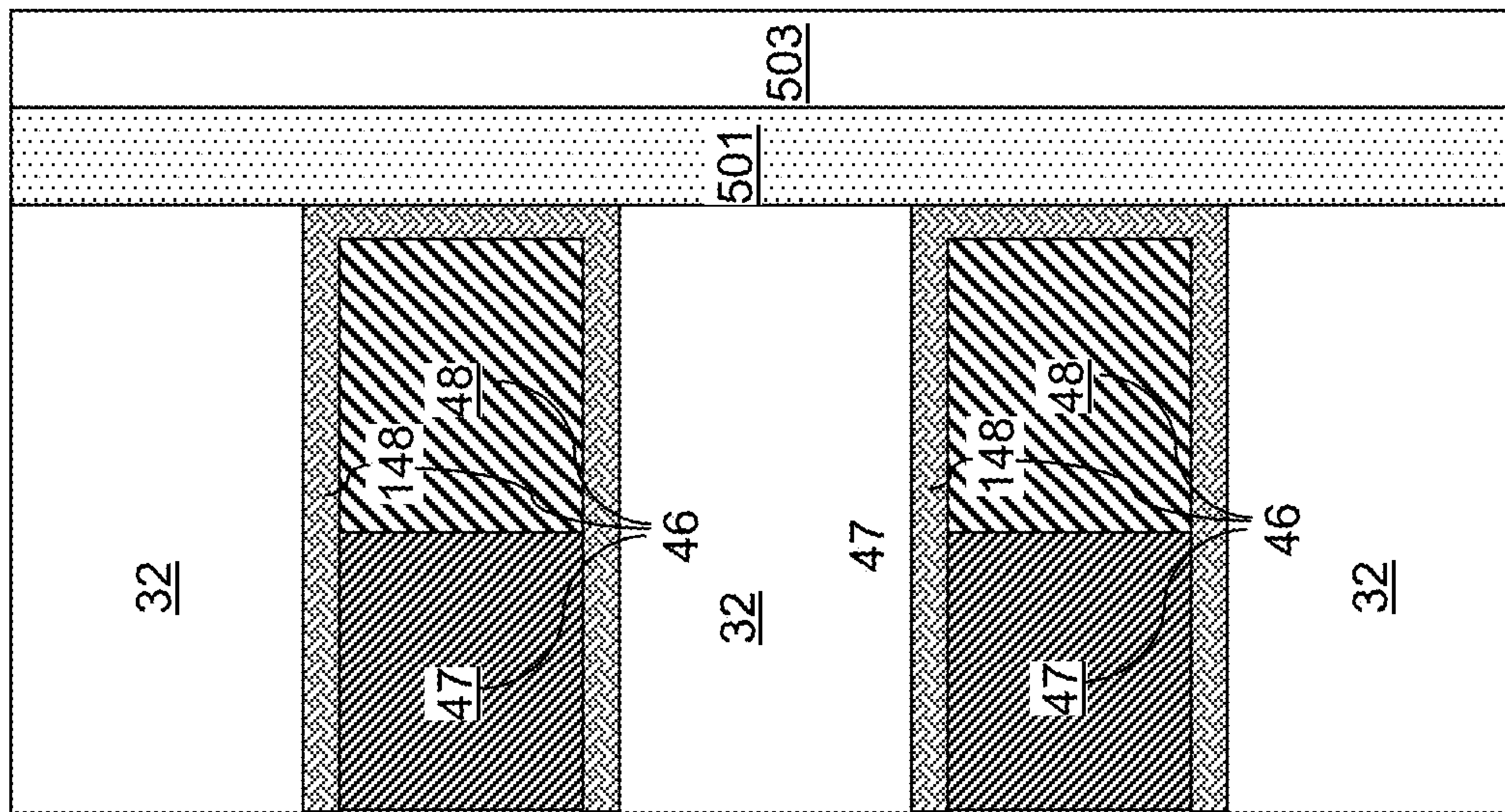

FIG. 12C

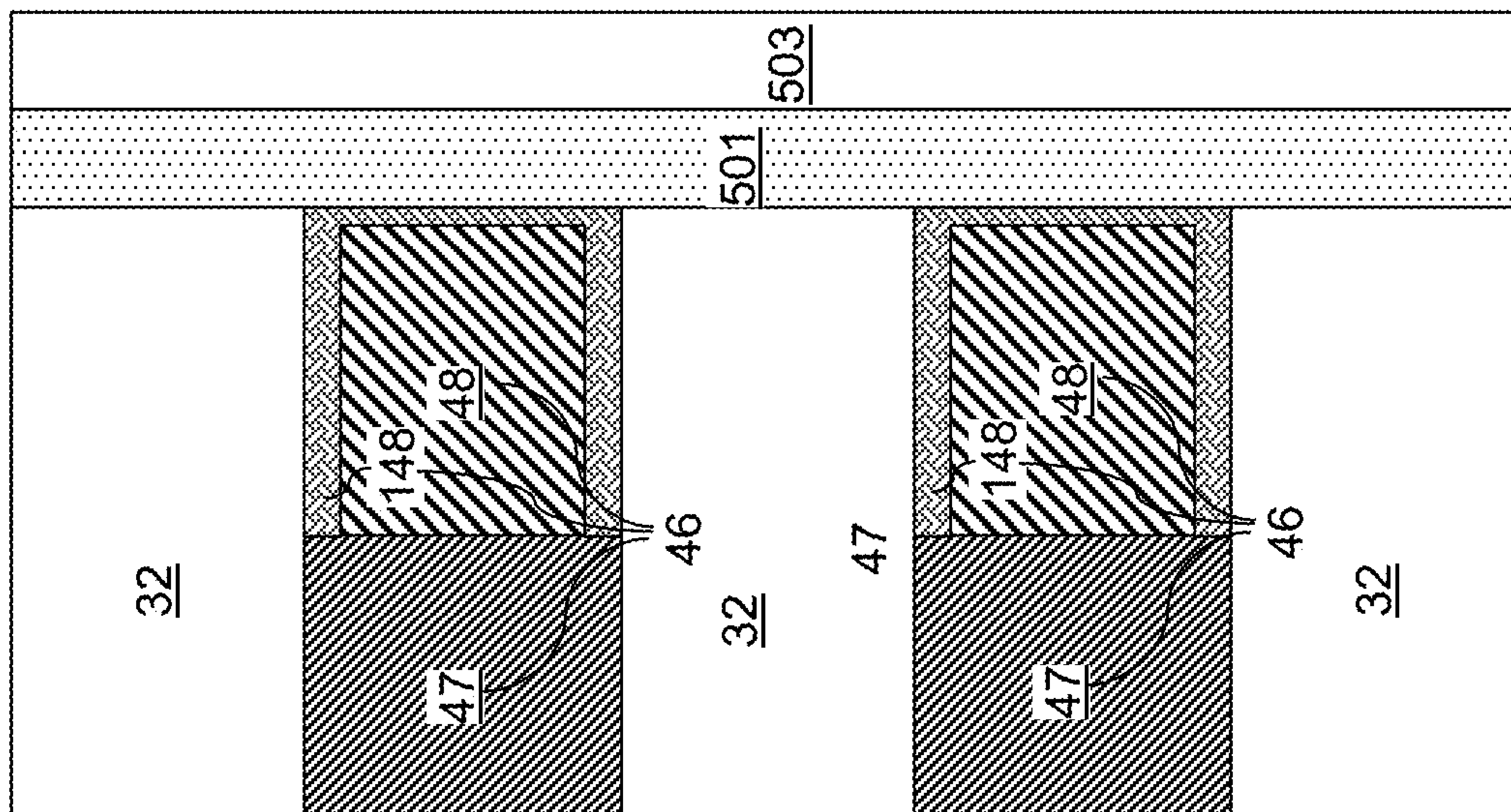

FIG. 13B

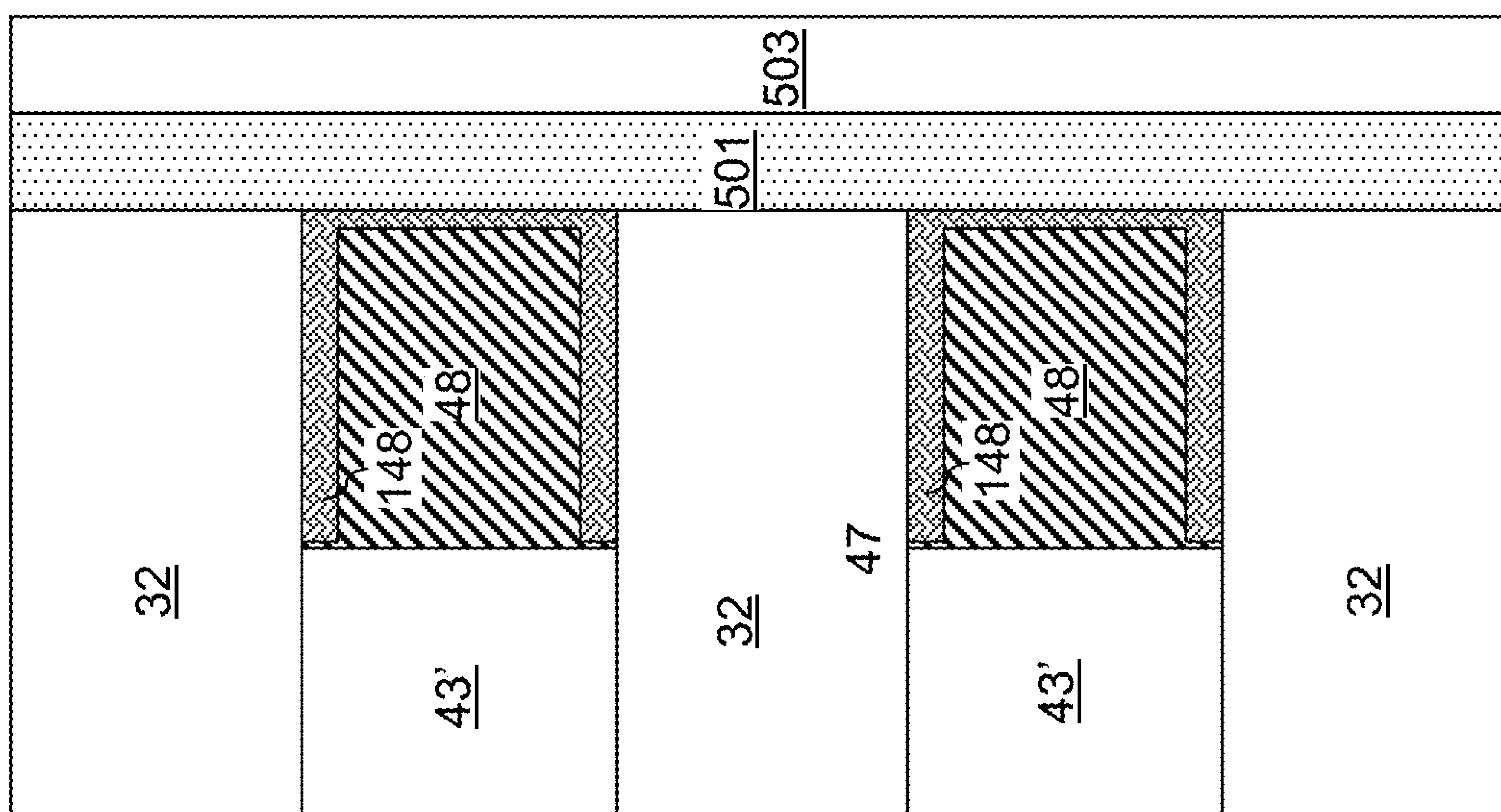

FIG. 13A

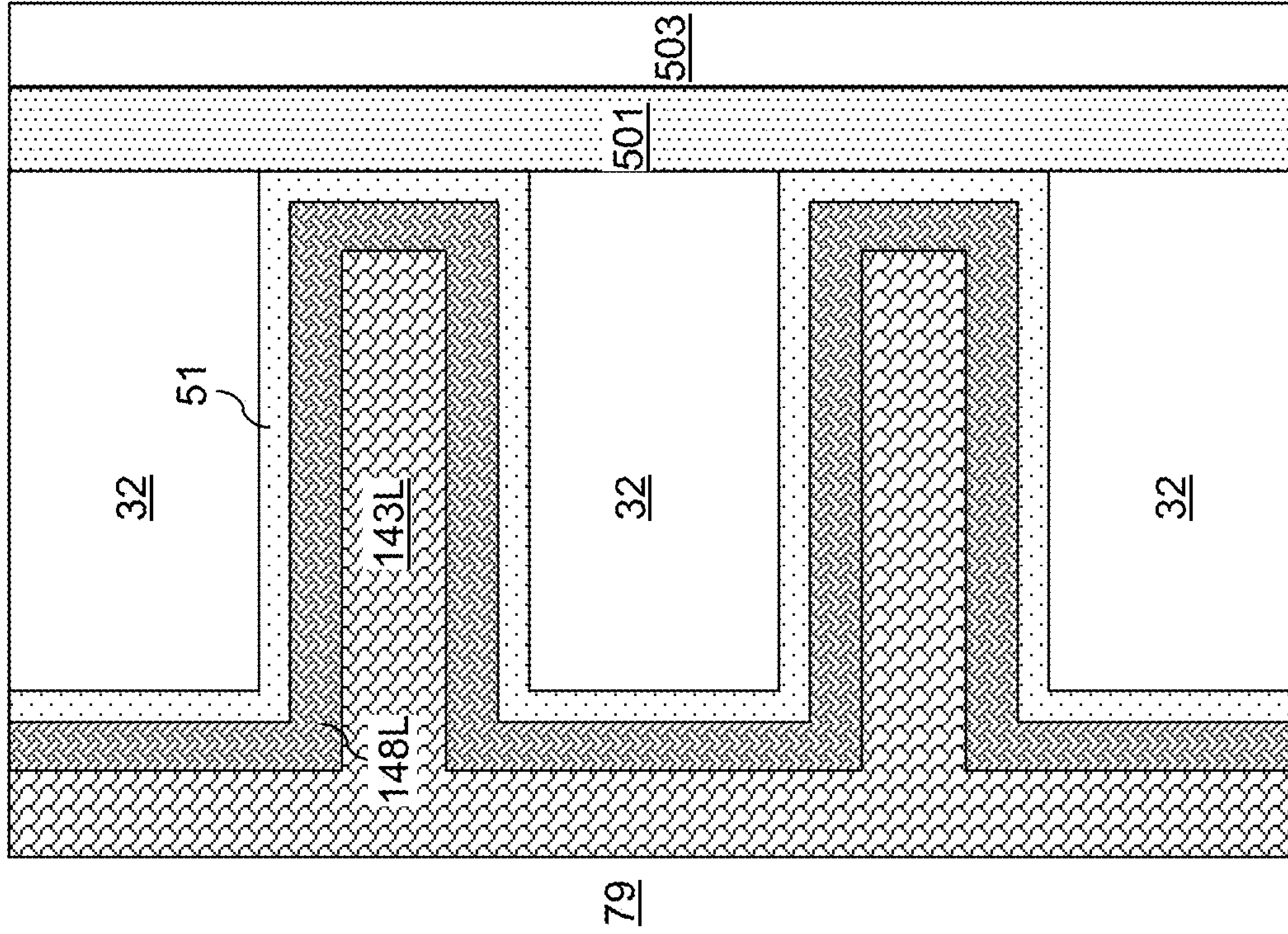

FIG. 14B

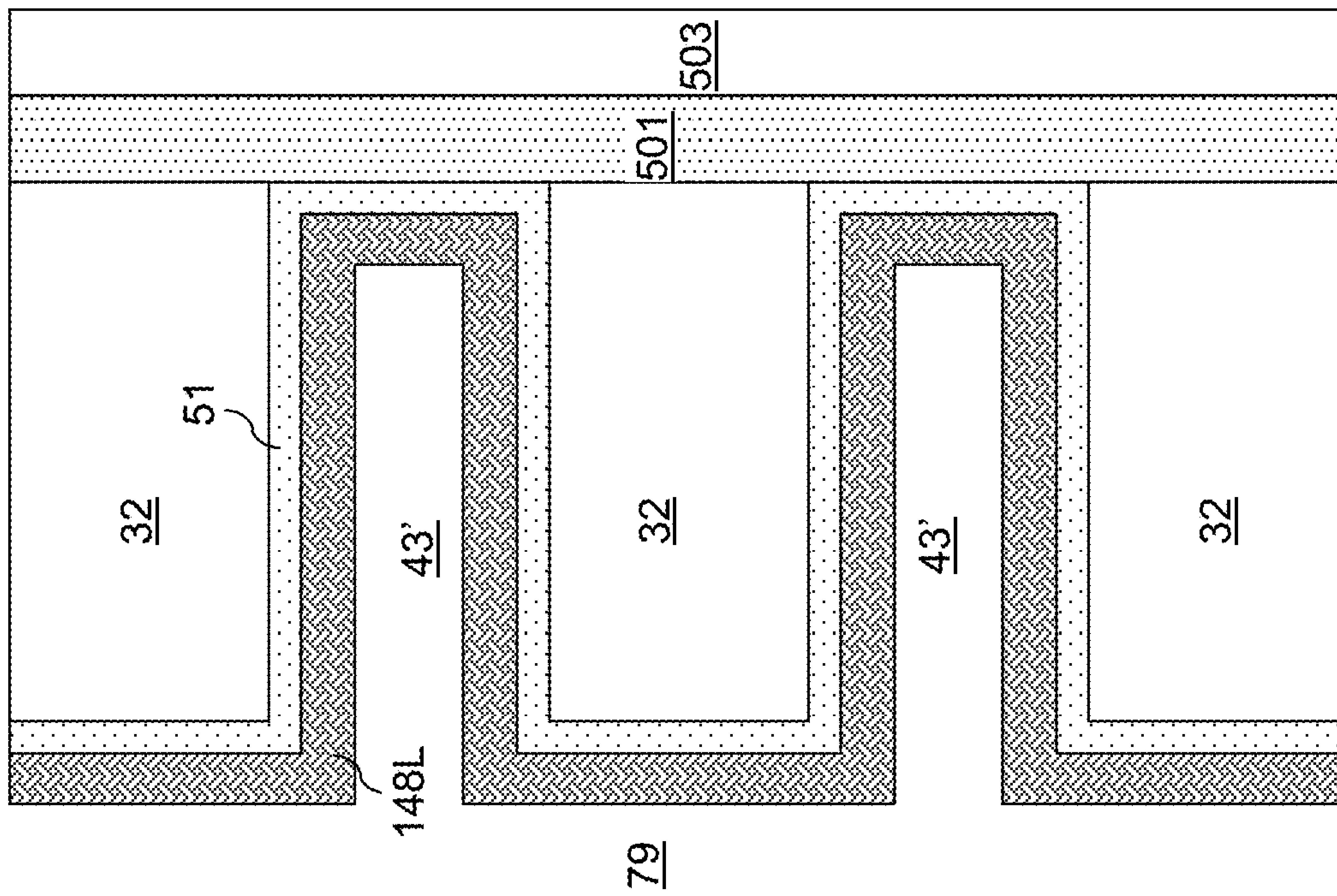

FIG. 14A

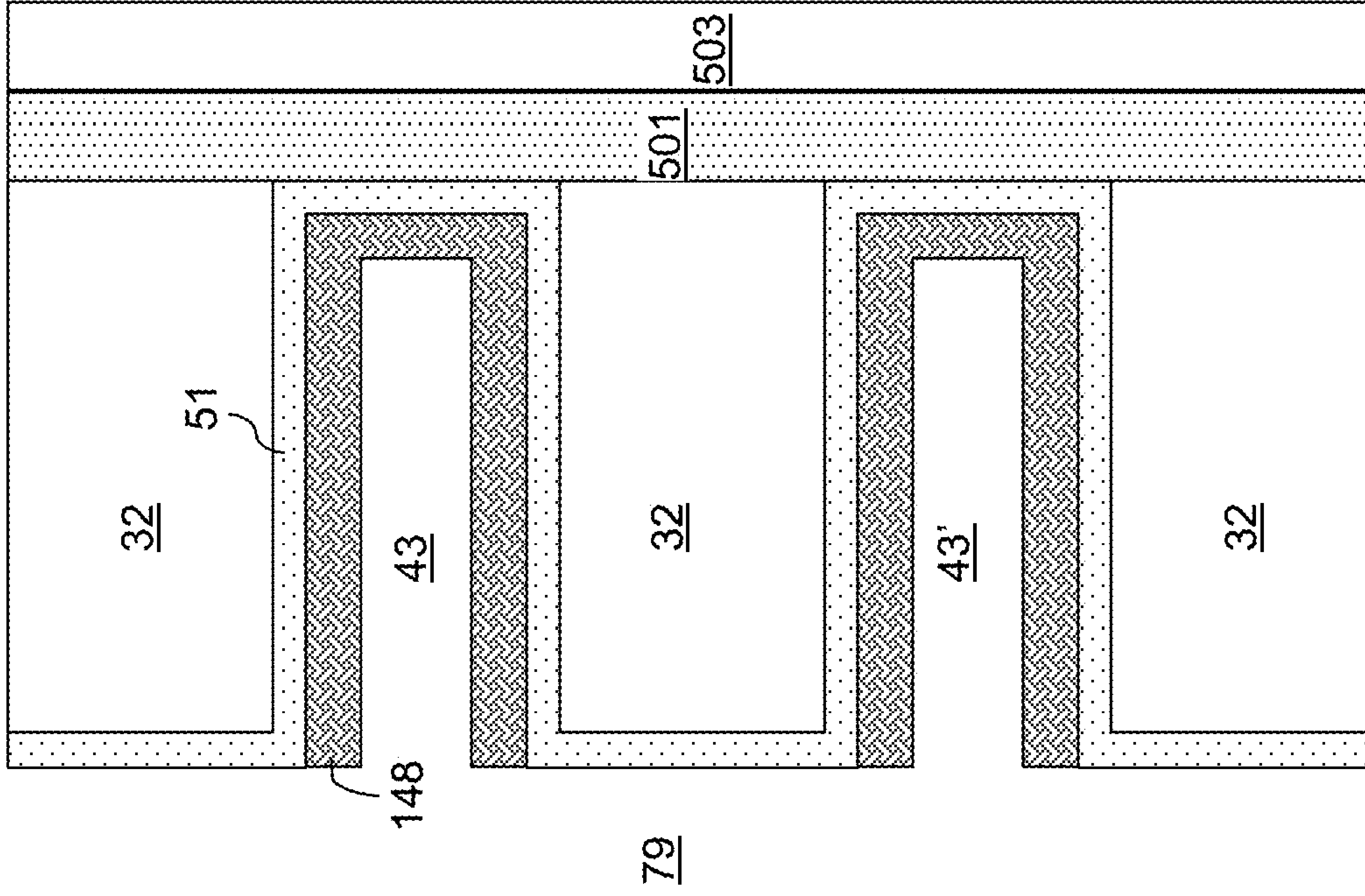

FIG. 14D

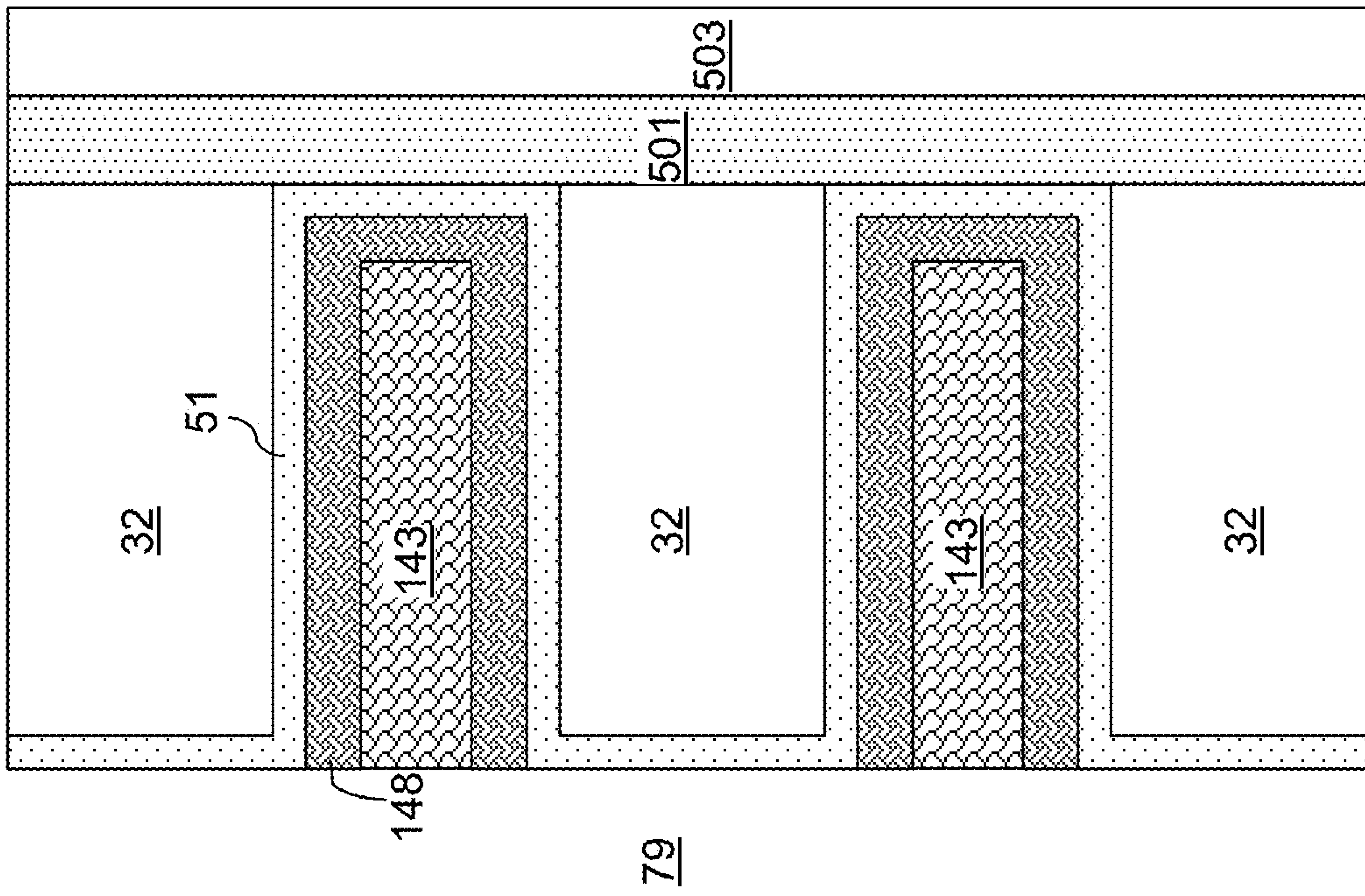

FIG. 14C

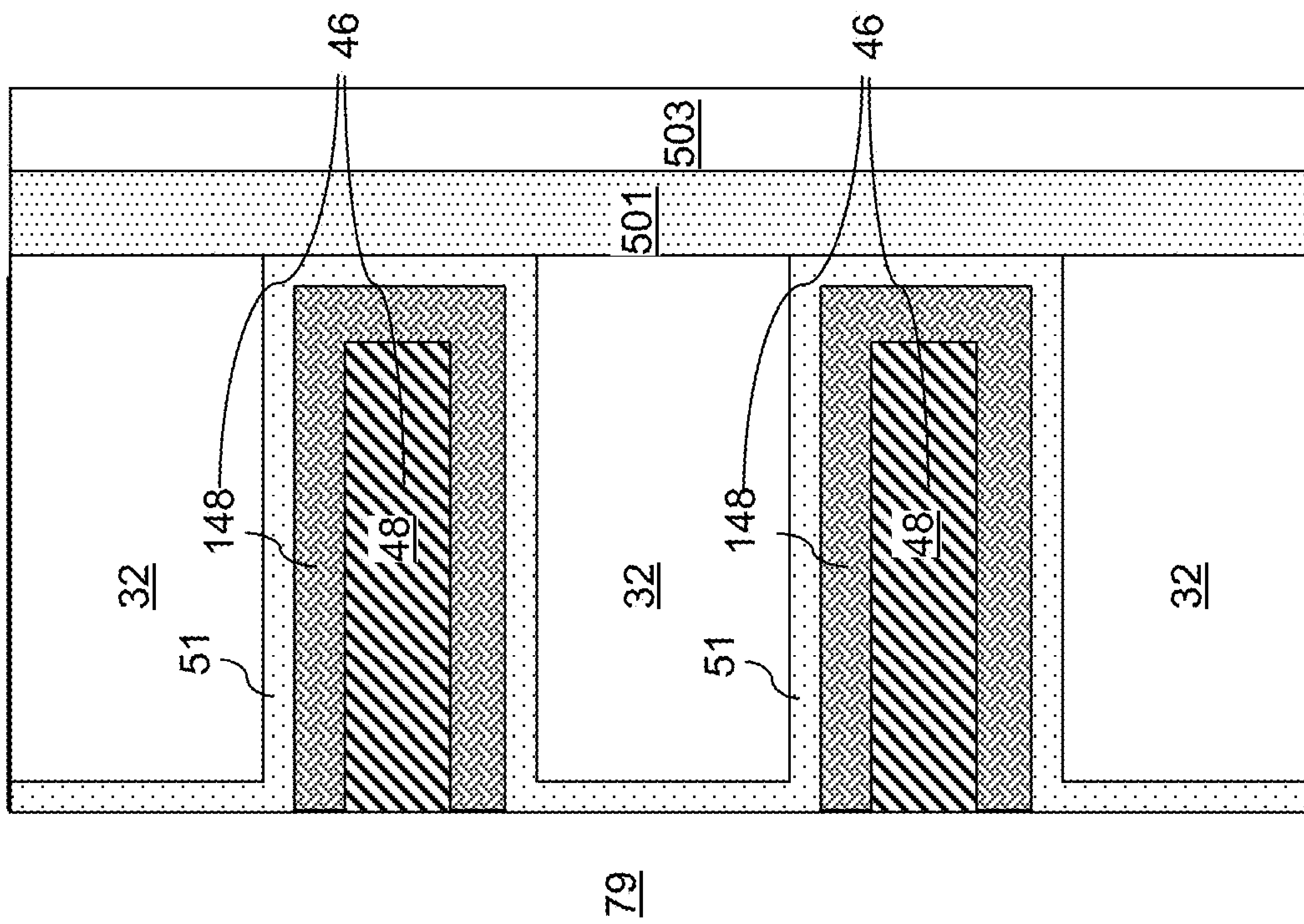

FIG. 14E

FIG. 15

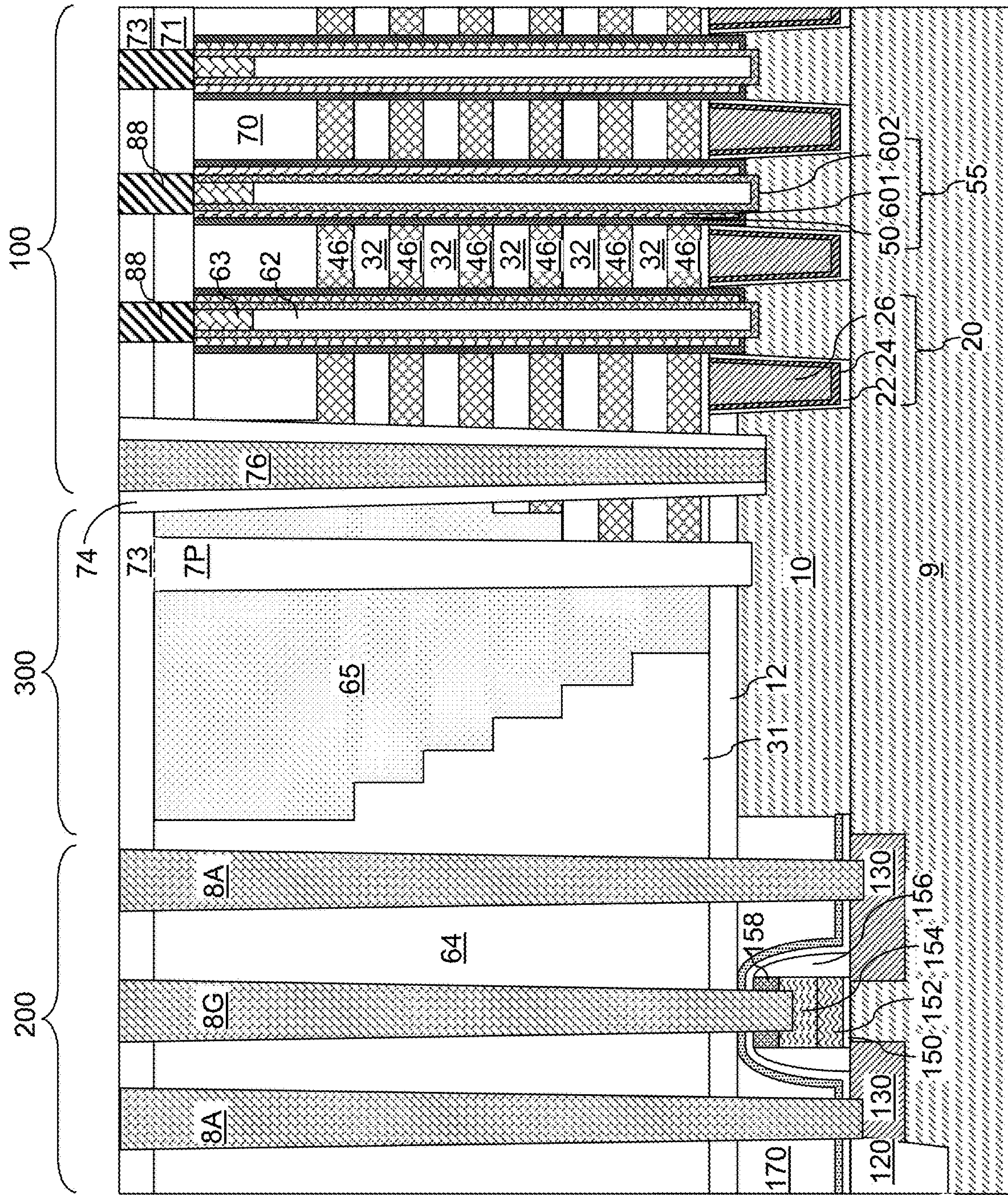

FIG. 16

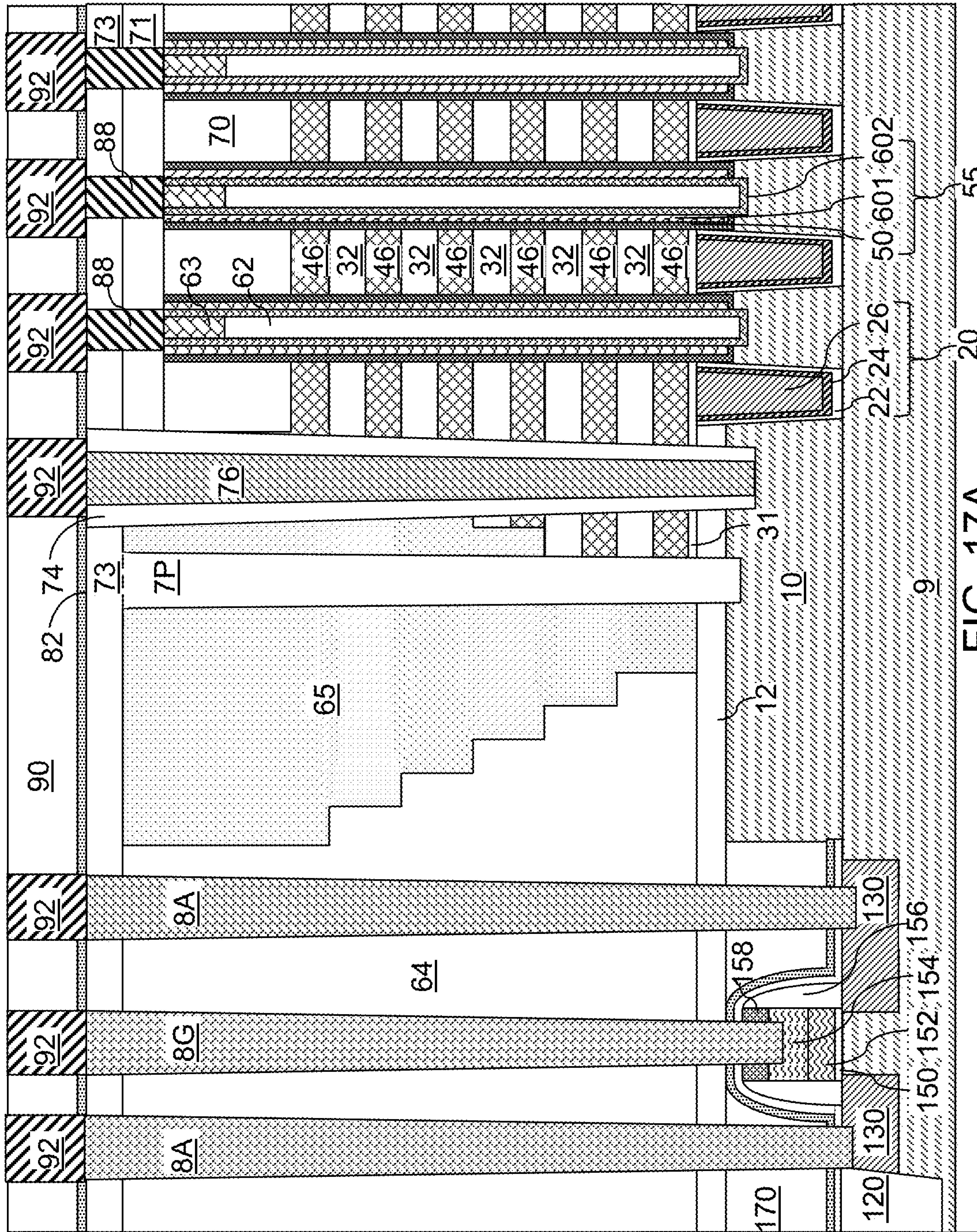

FIG. 17A

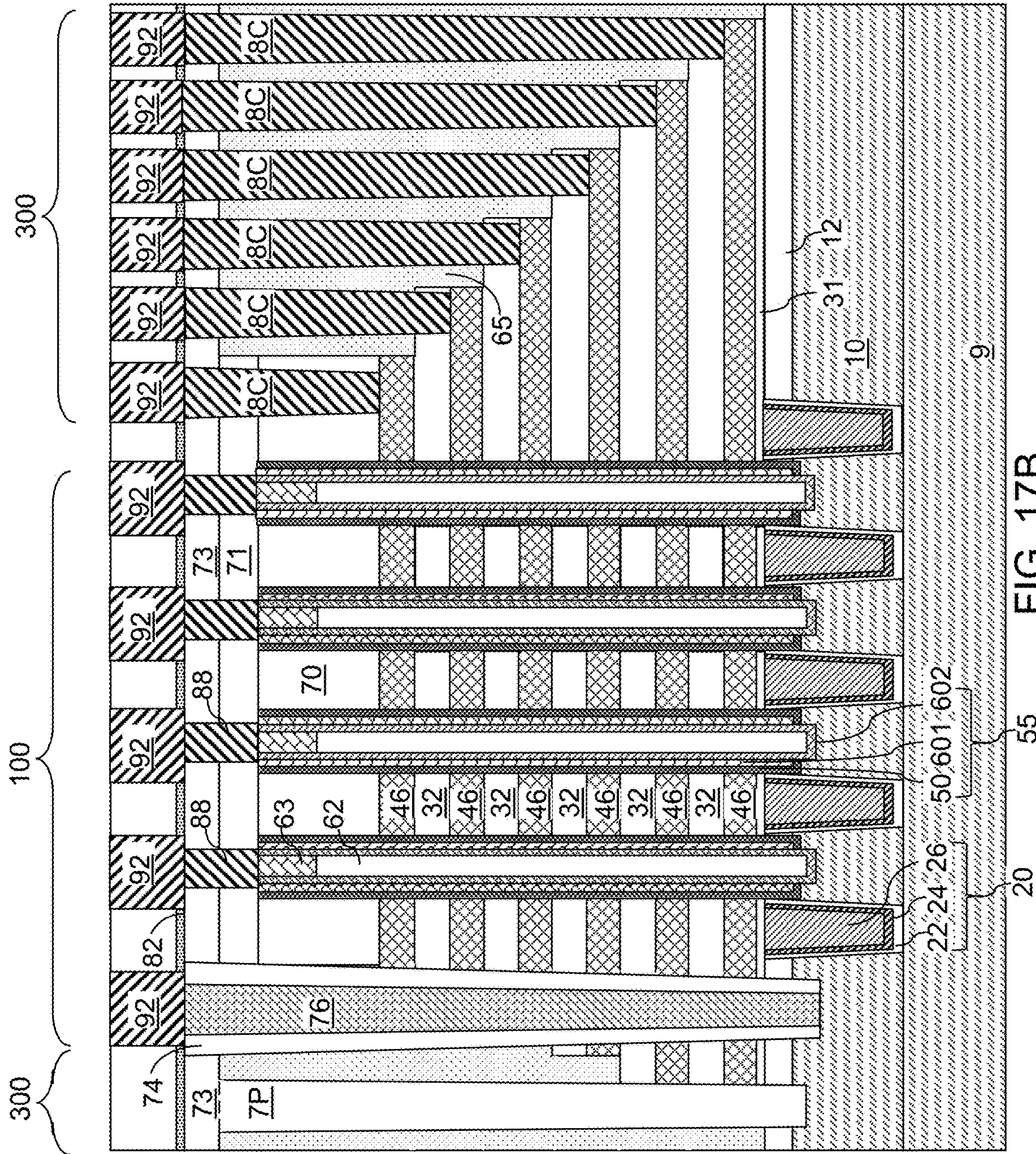

FIG. 17B

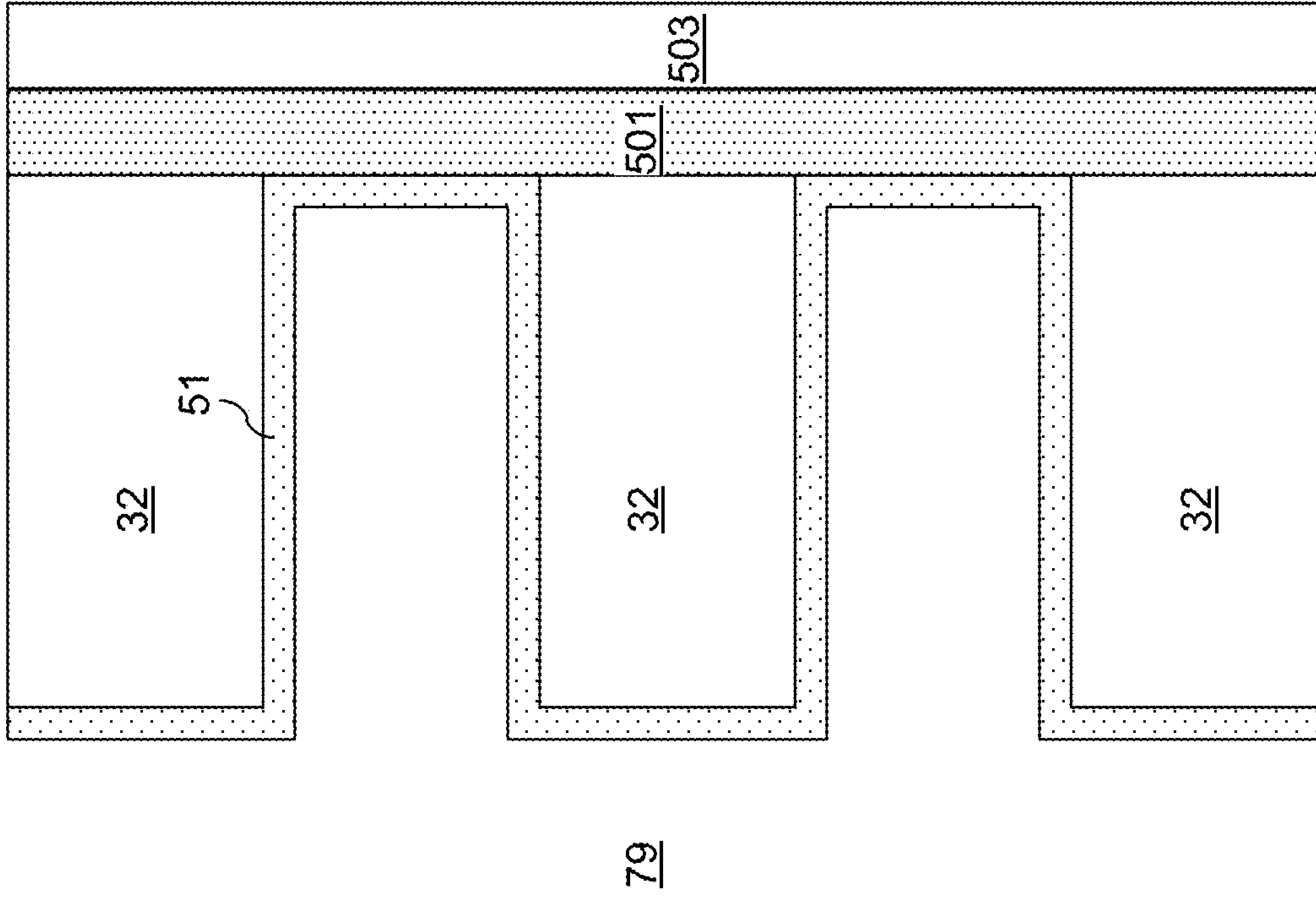

FIG. 18B

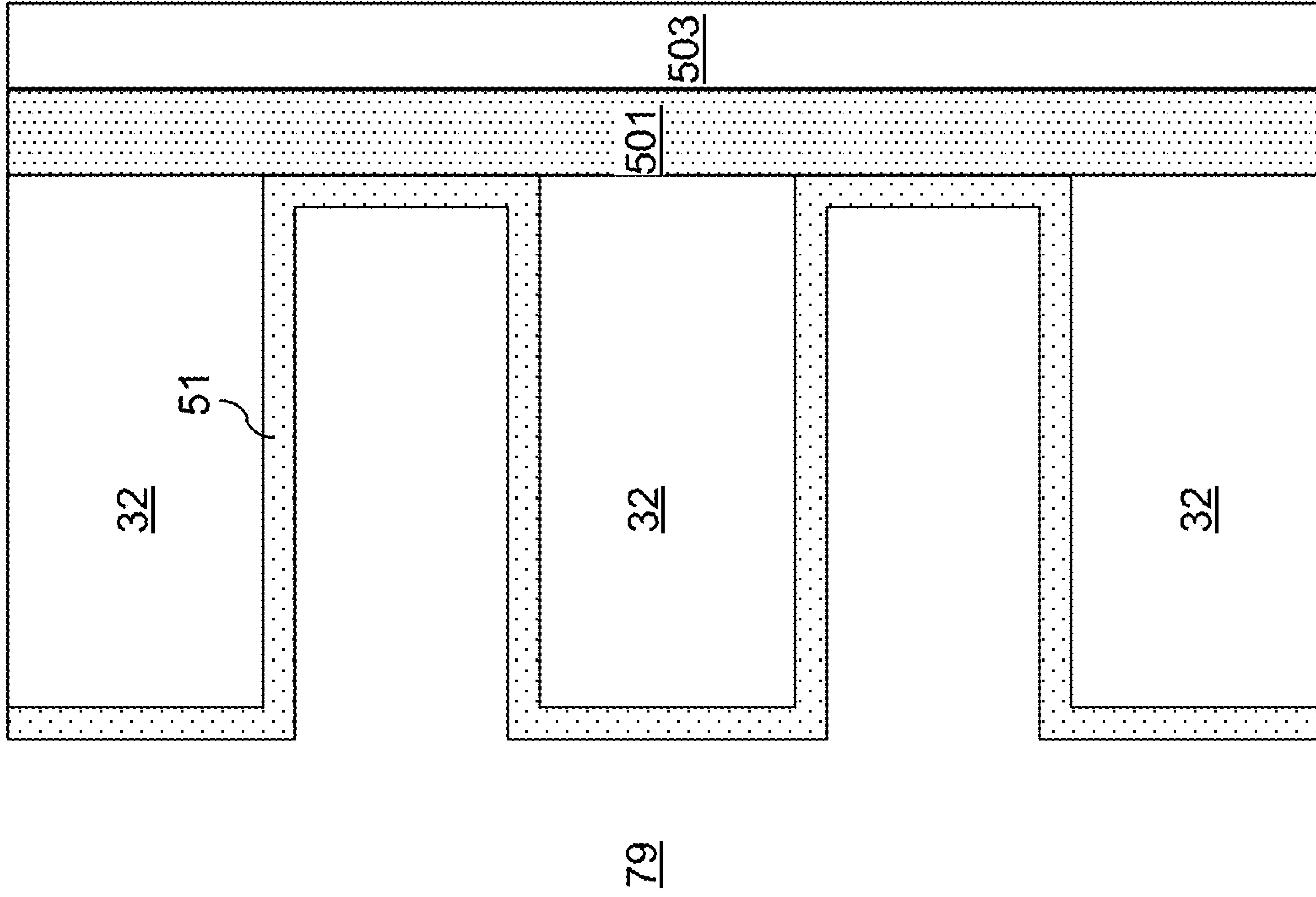

FIG. 18A

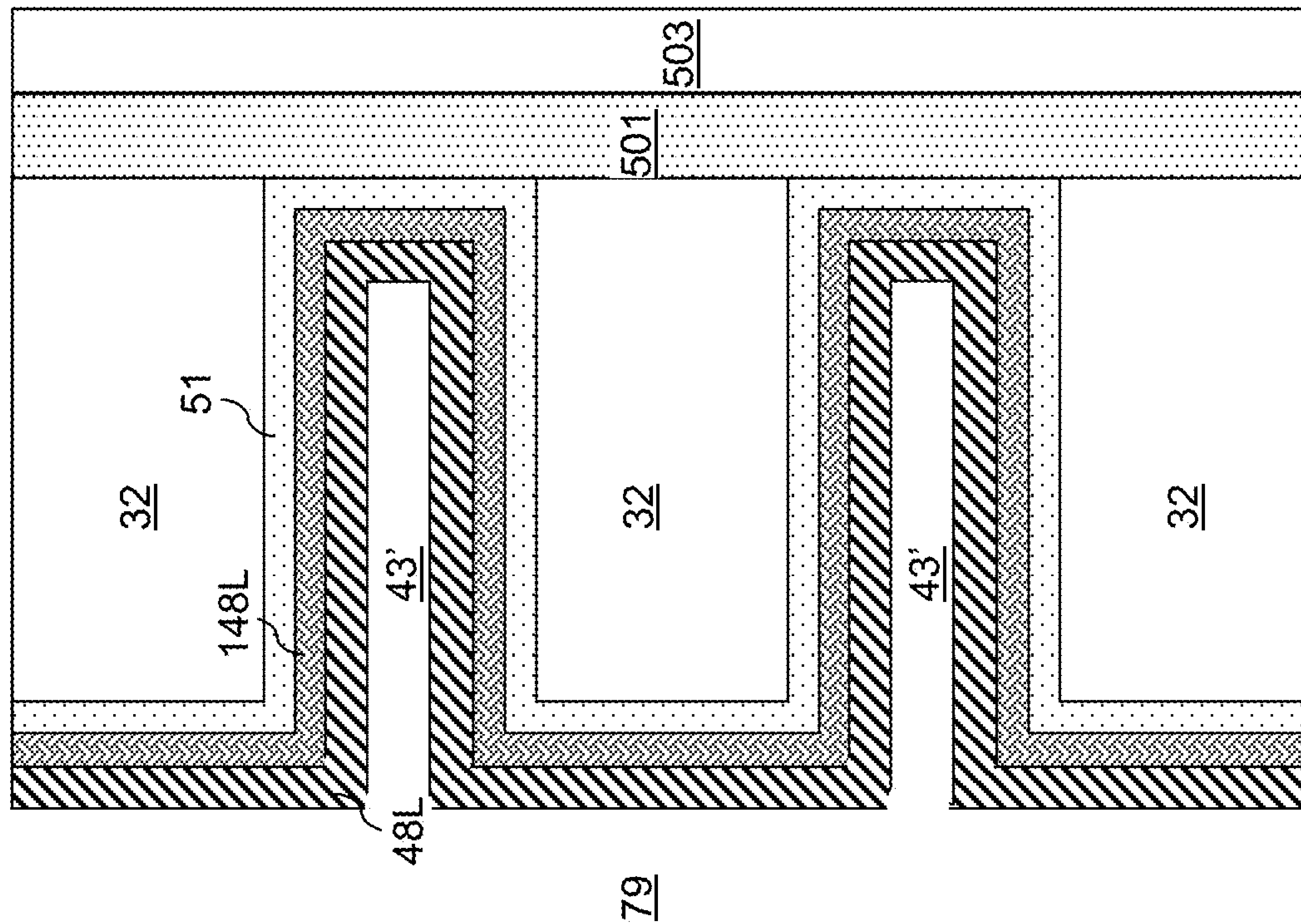

FIG. 18D

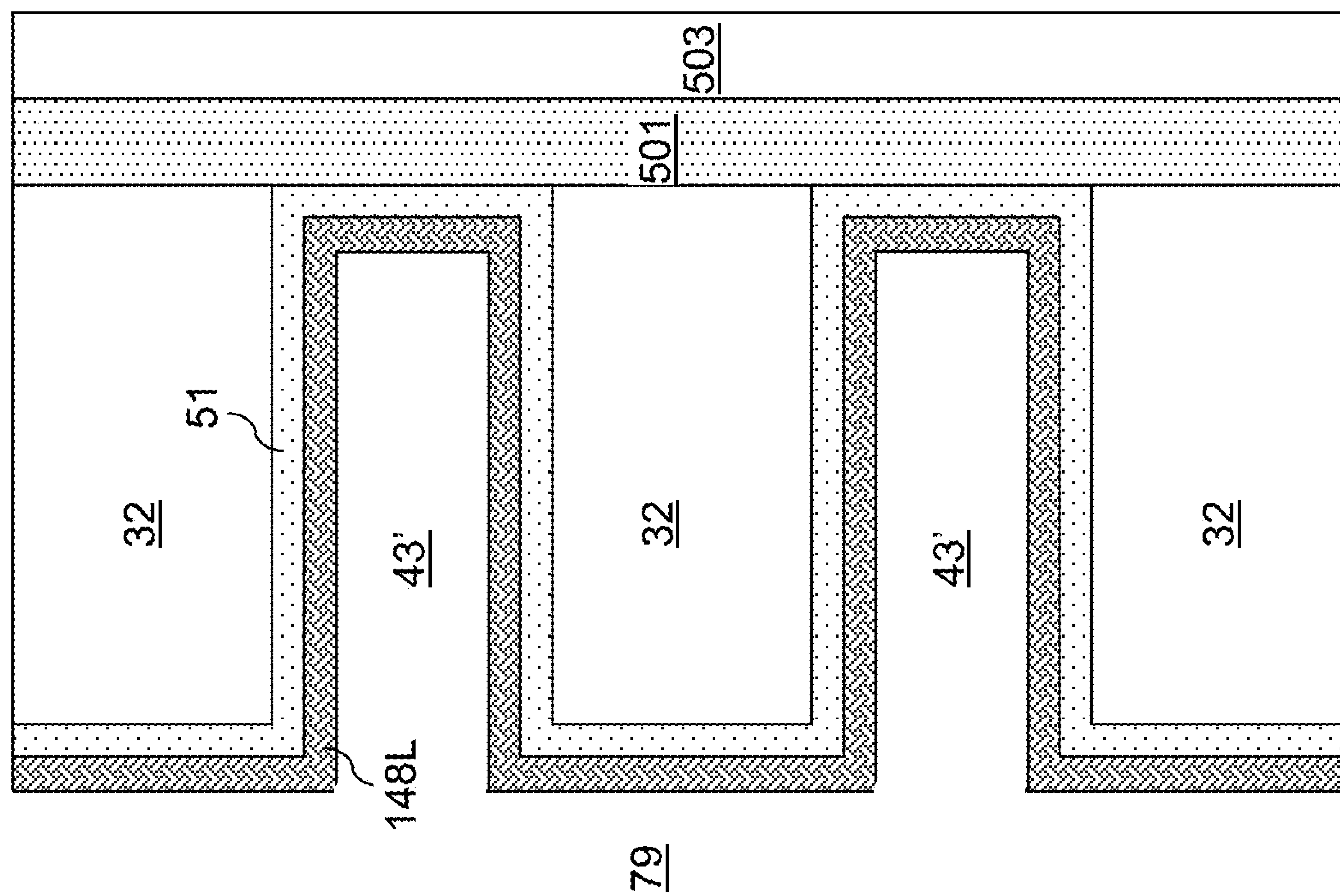

FIG. 18C

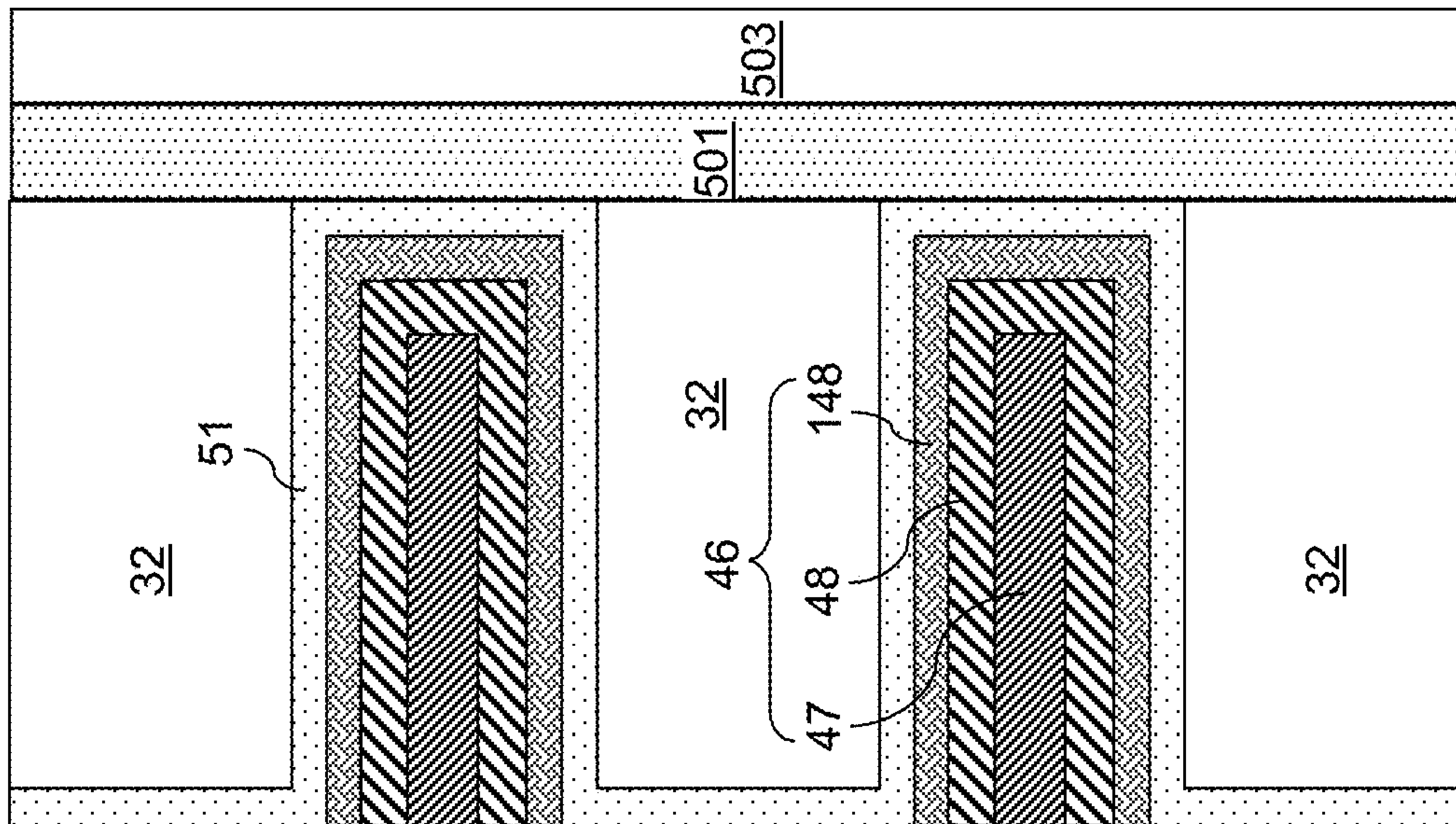

FIG. 18F

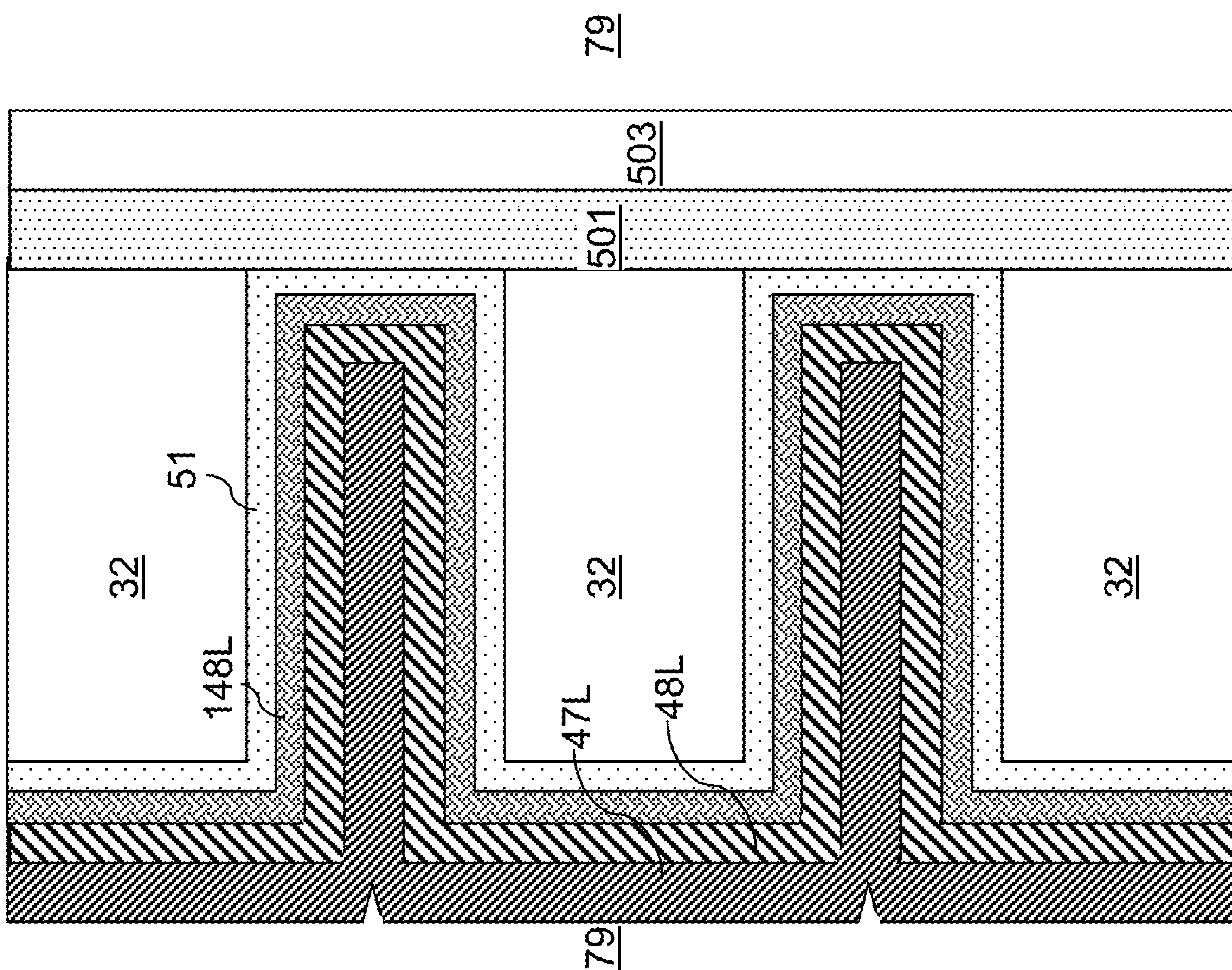

FIG. 18E

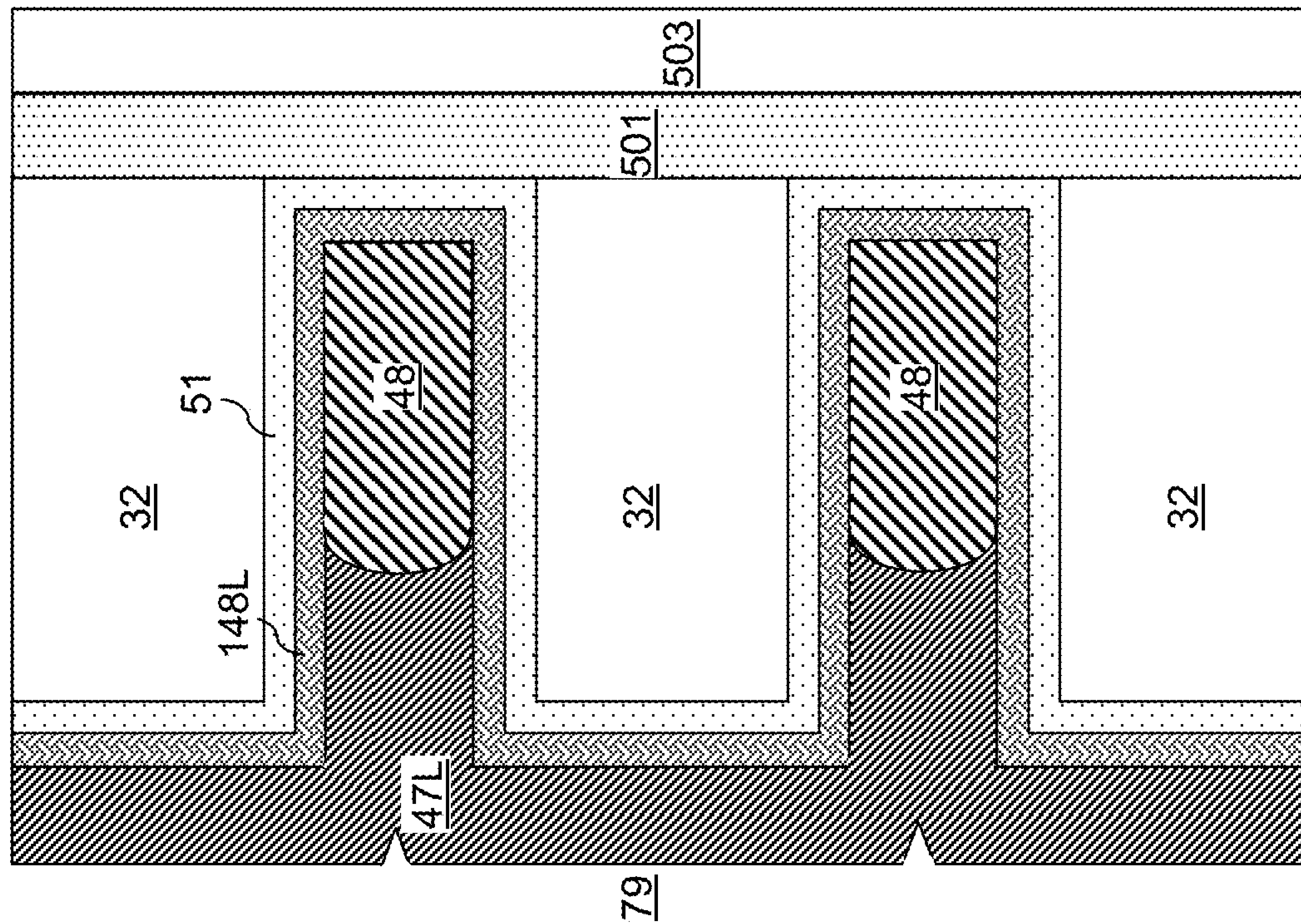

FIG. 19B

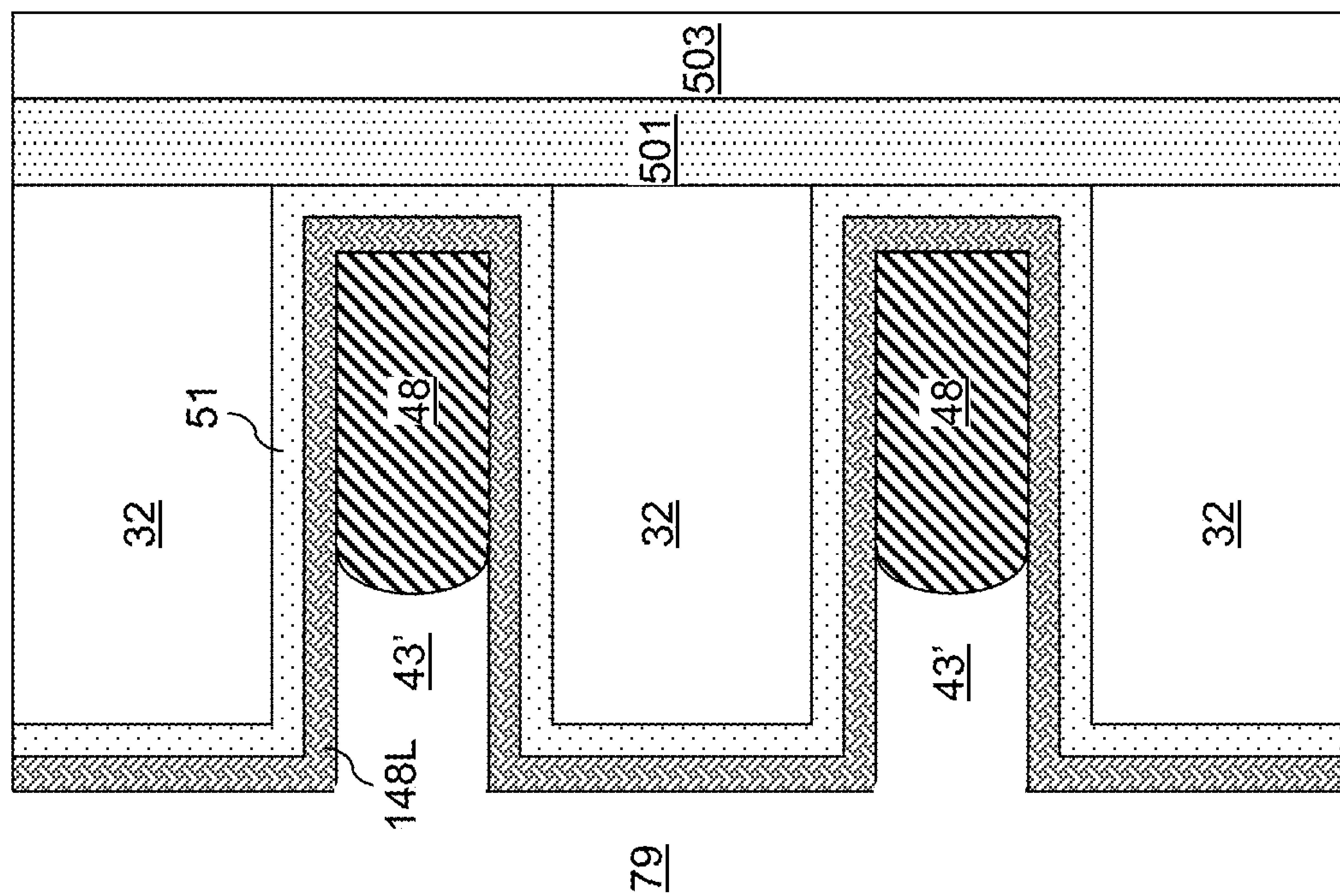

FIG. 19A

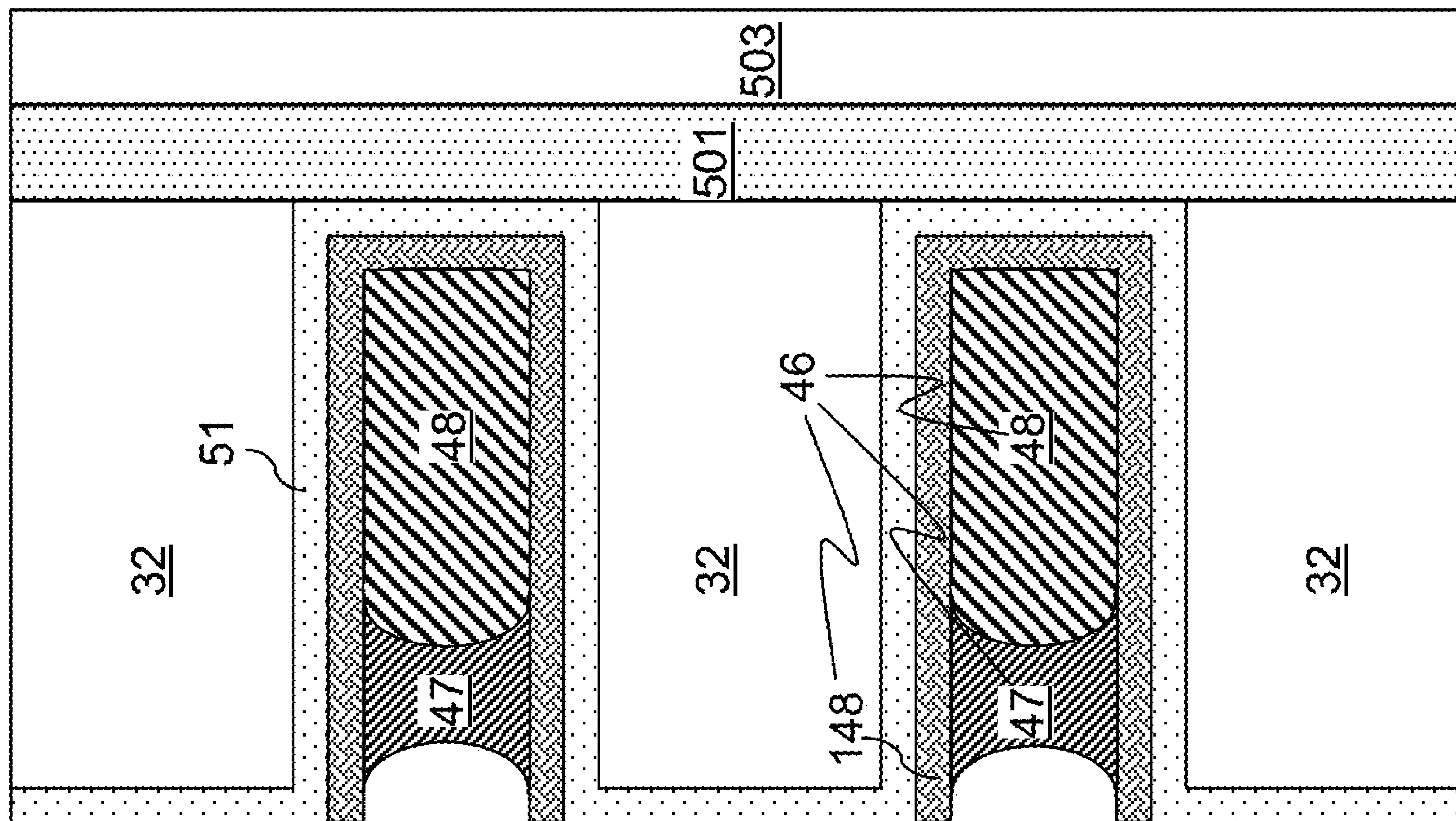

FIG. 19D

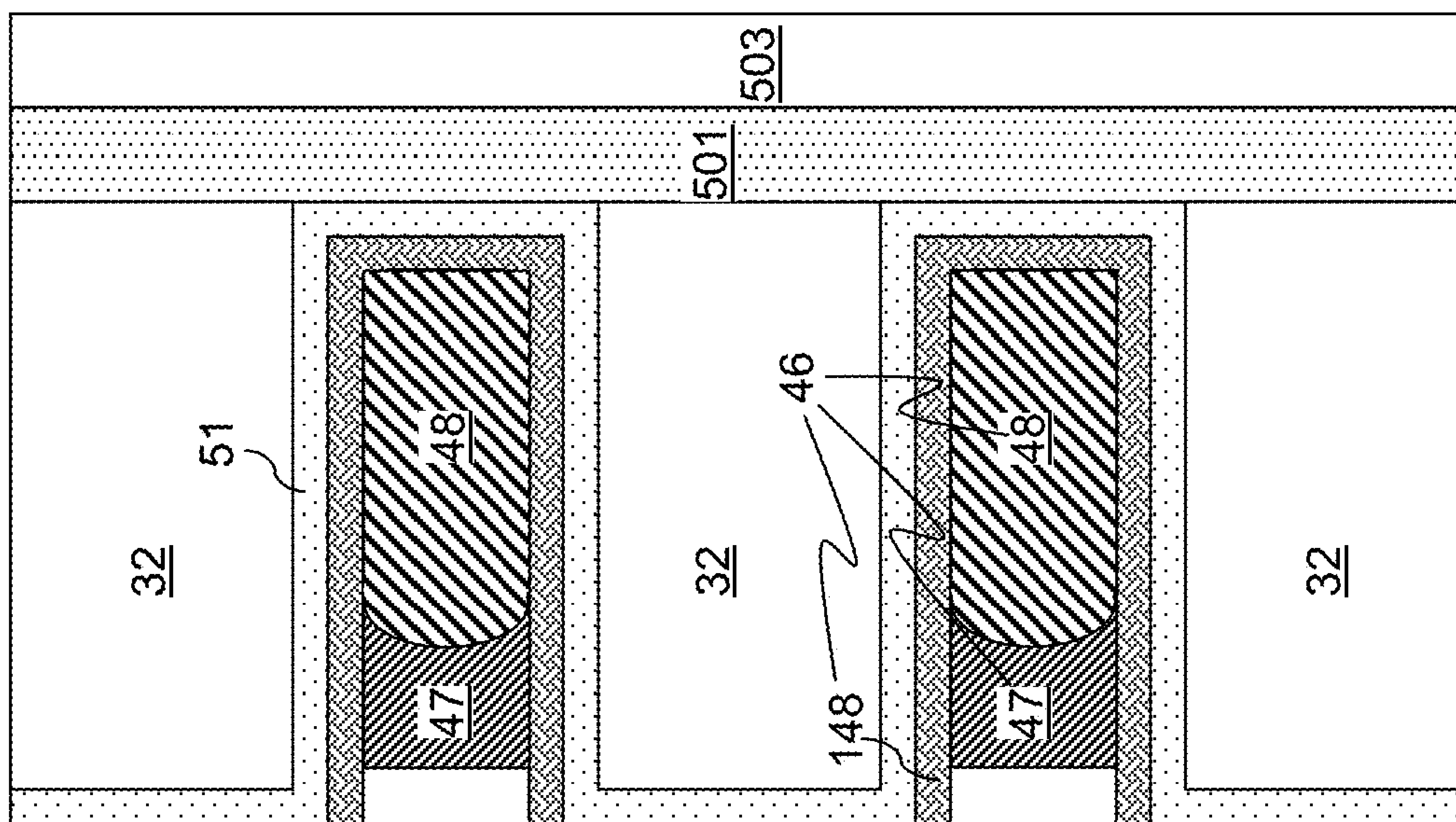

FIG. 19C

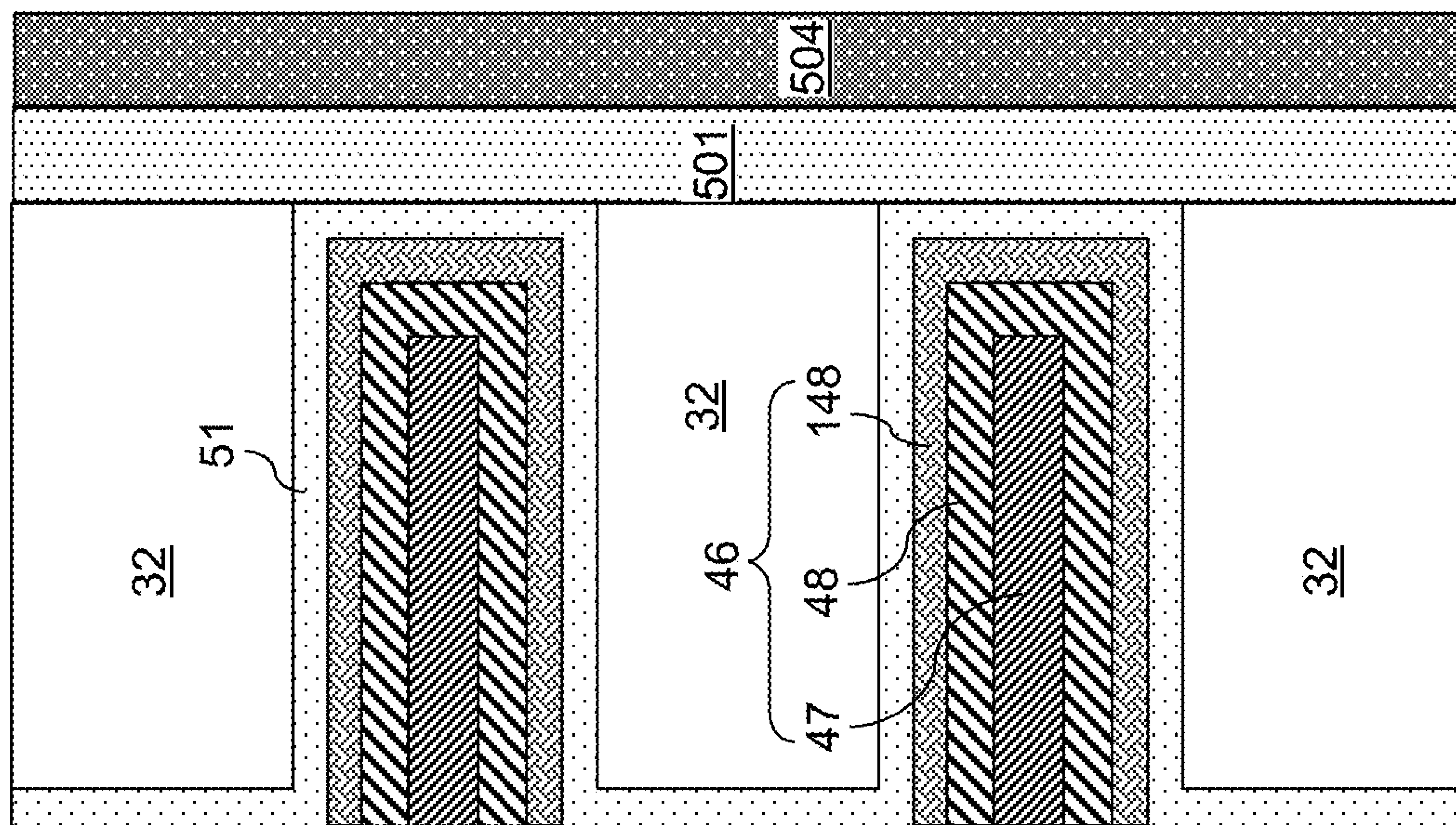

FIG. 20B

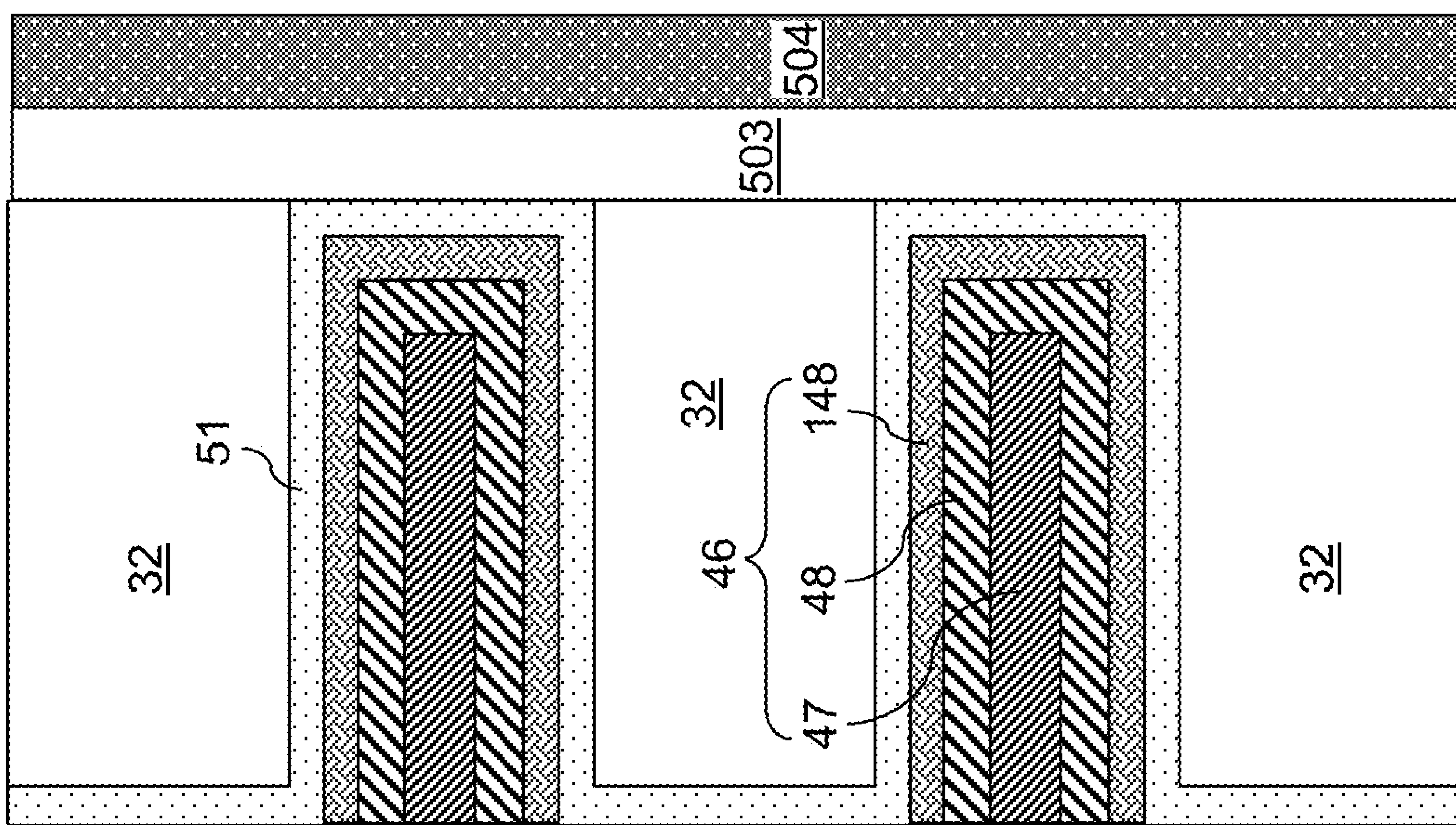

FIG. 20A

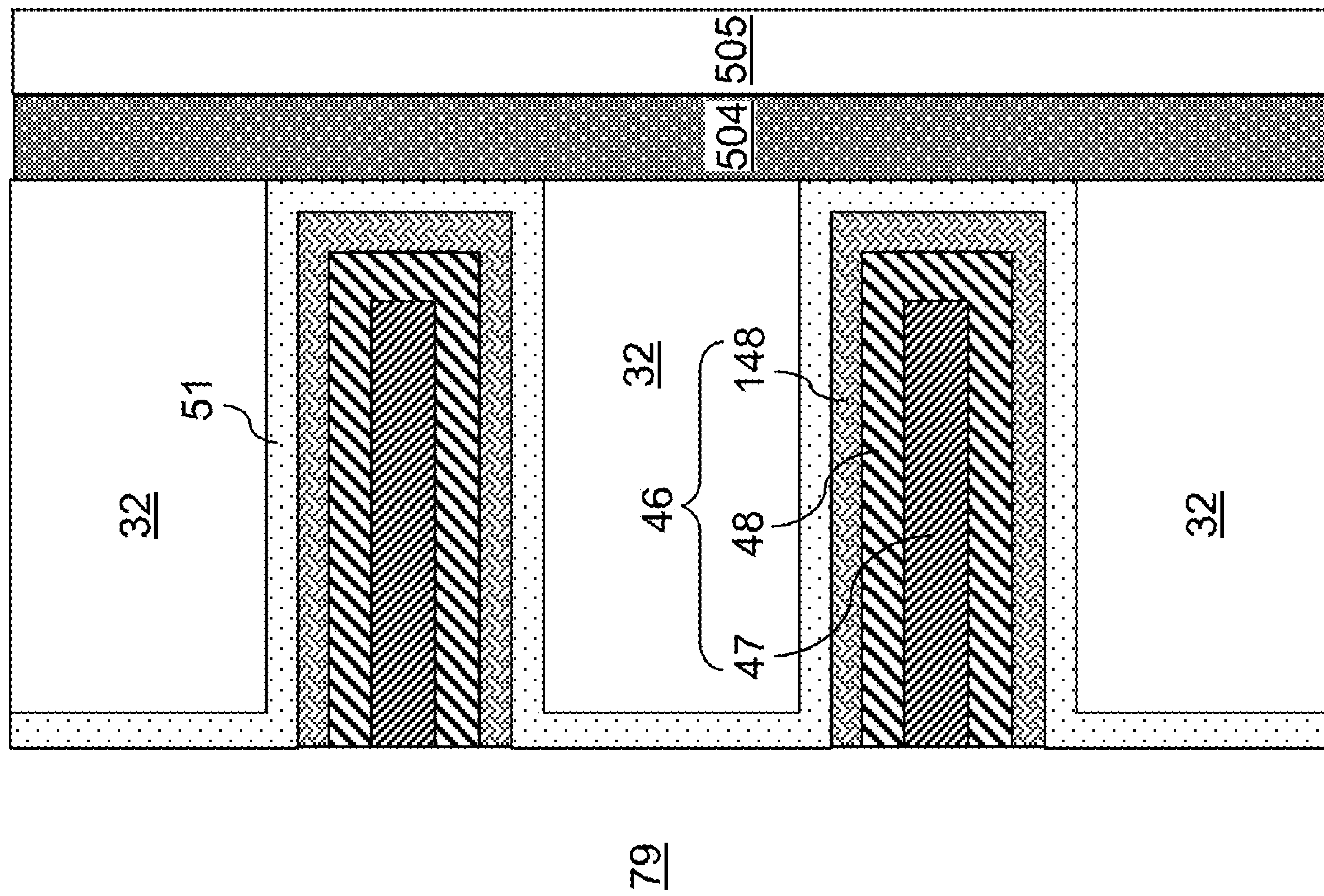

FIG. 20C

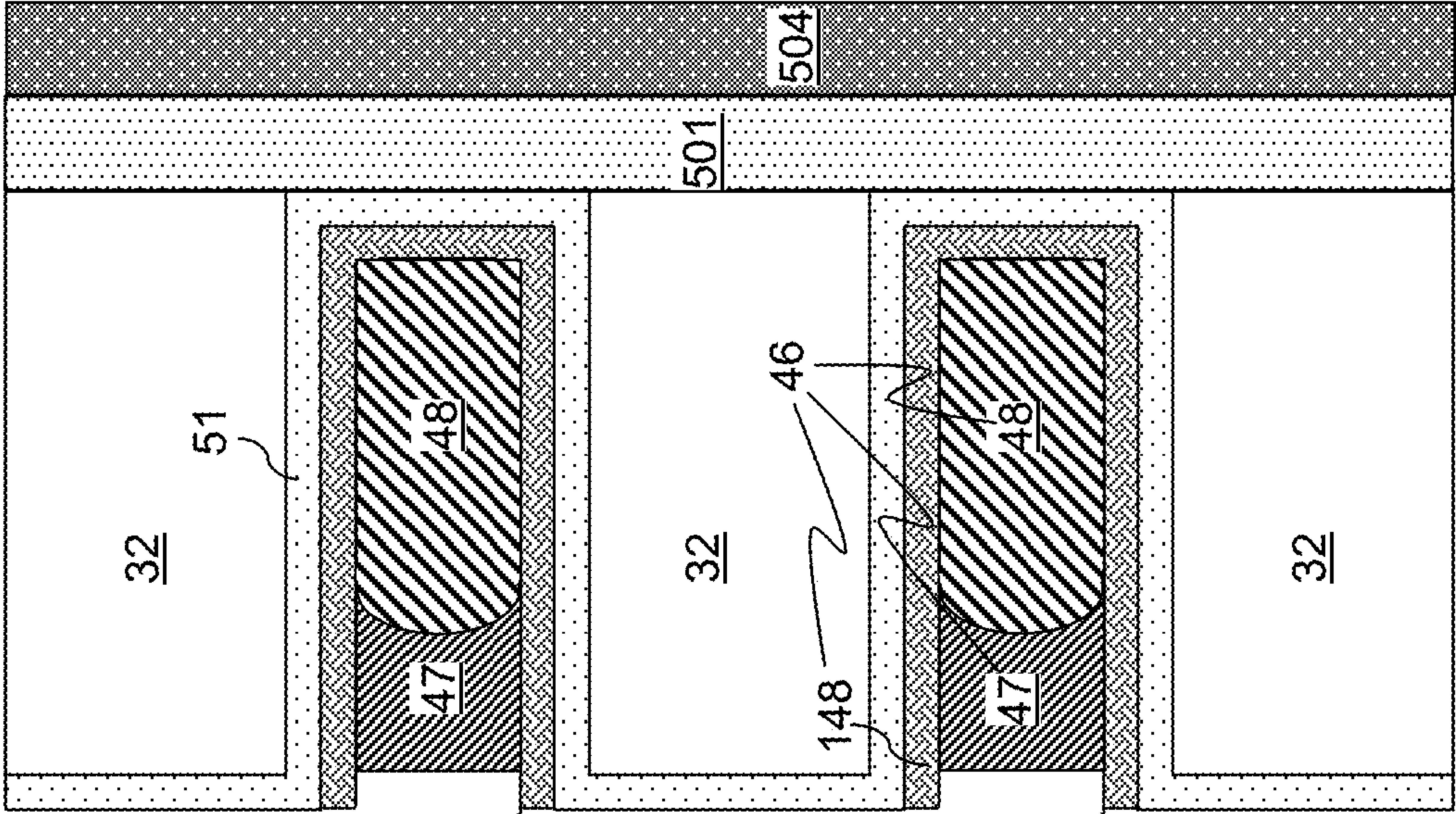

FIG. 21B

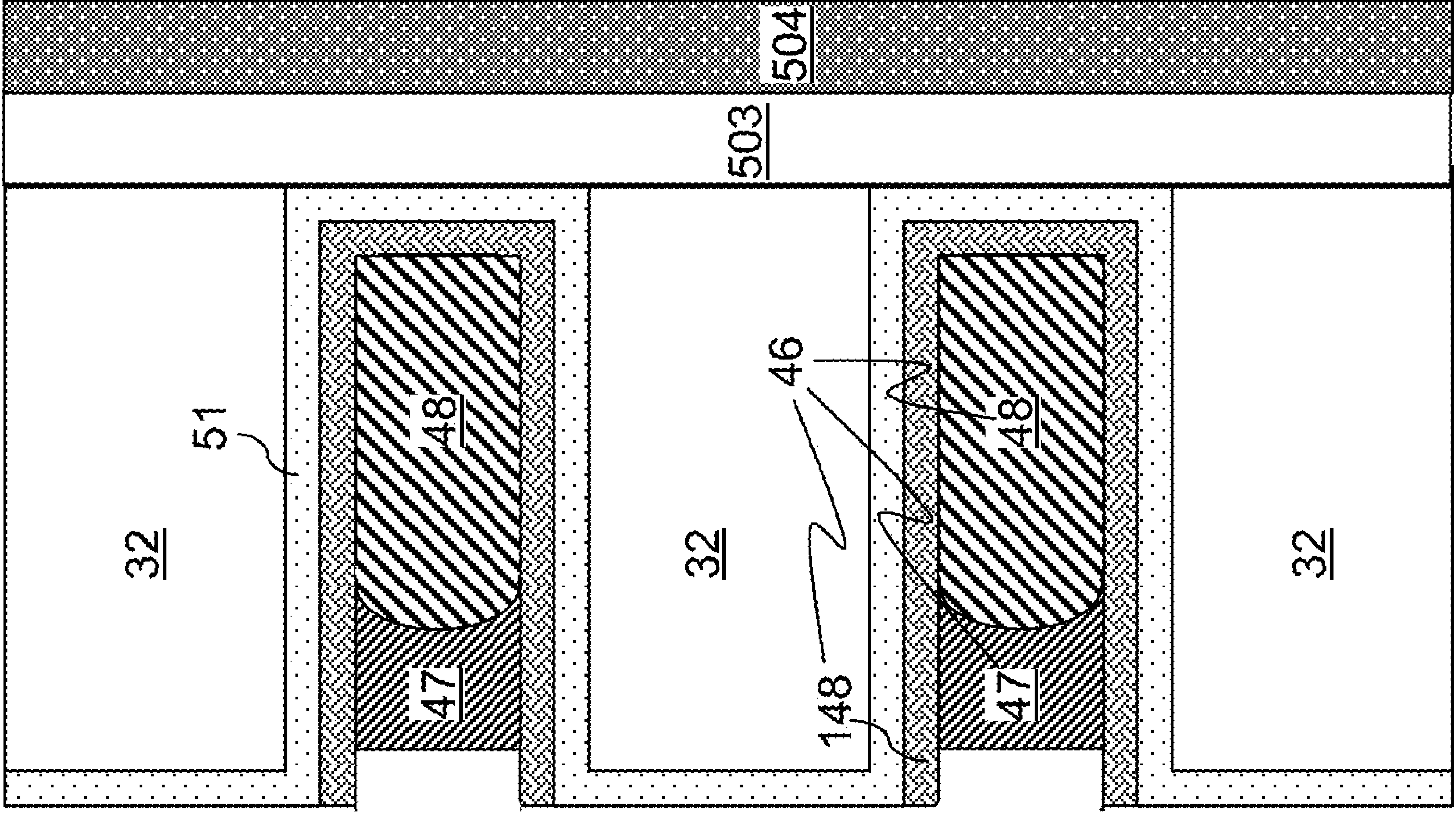

FIG. 21A

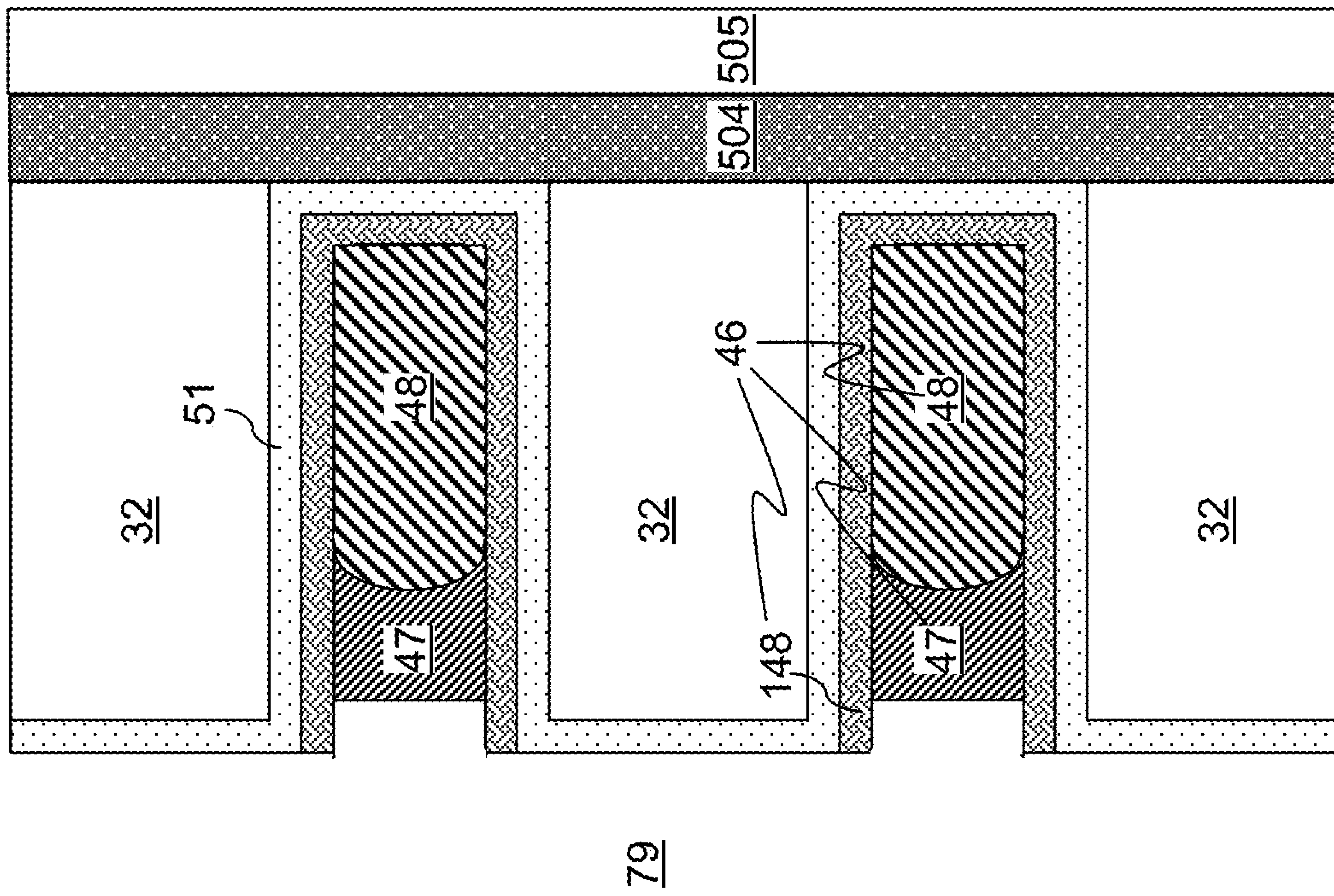

FIG. 21C

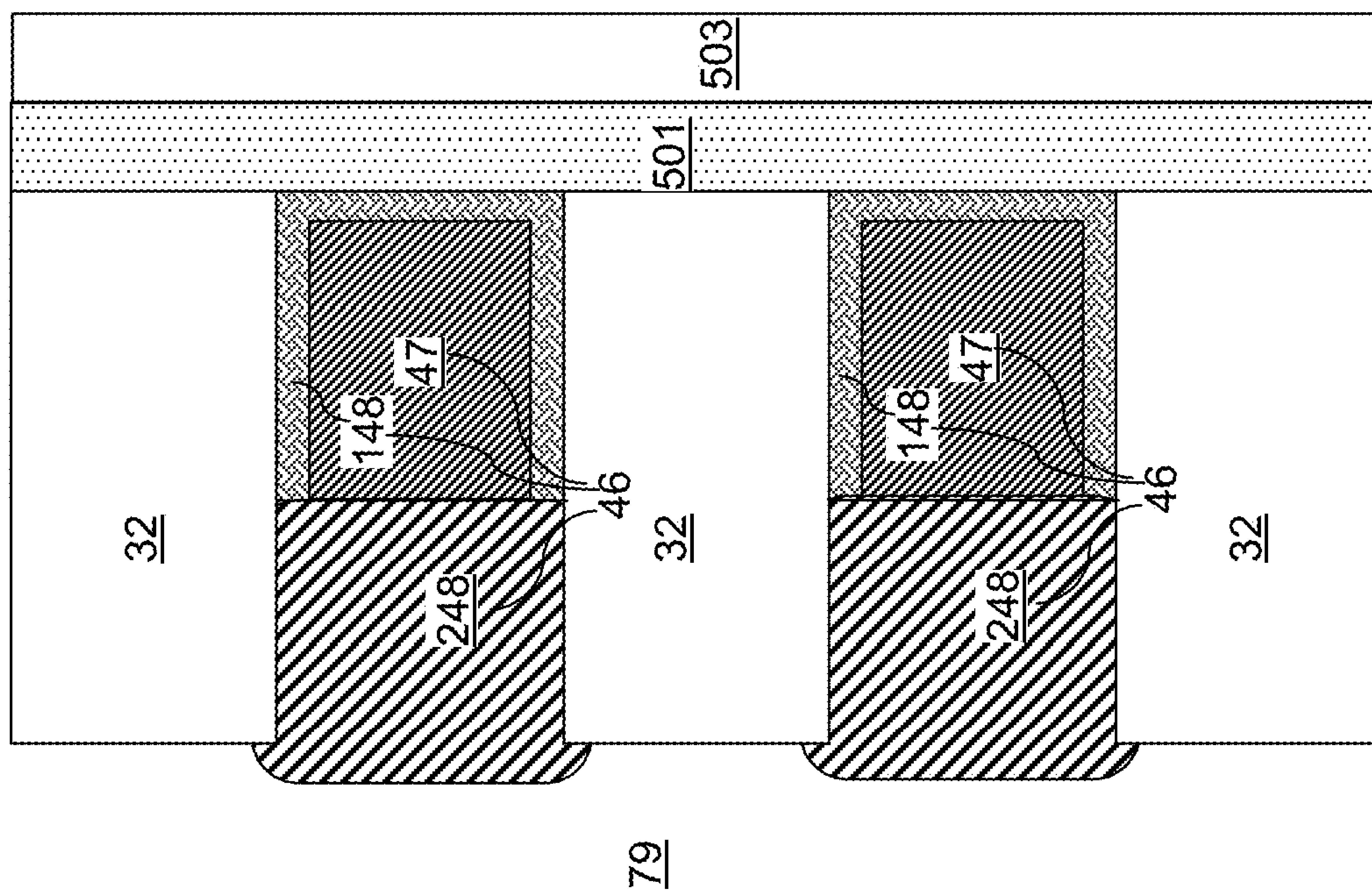

FIG. 22B

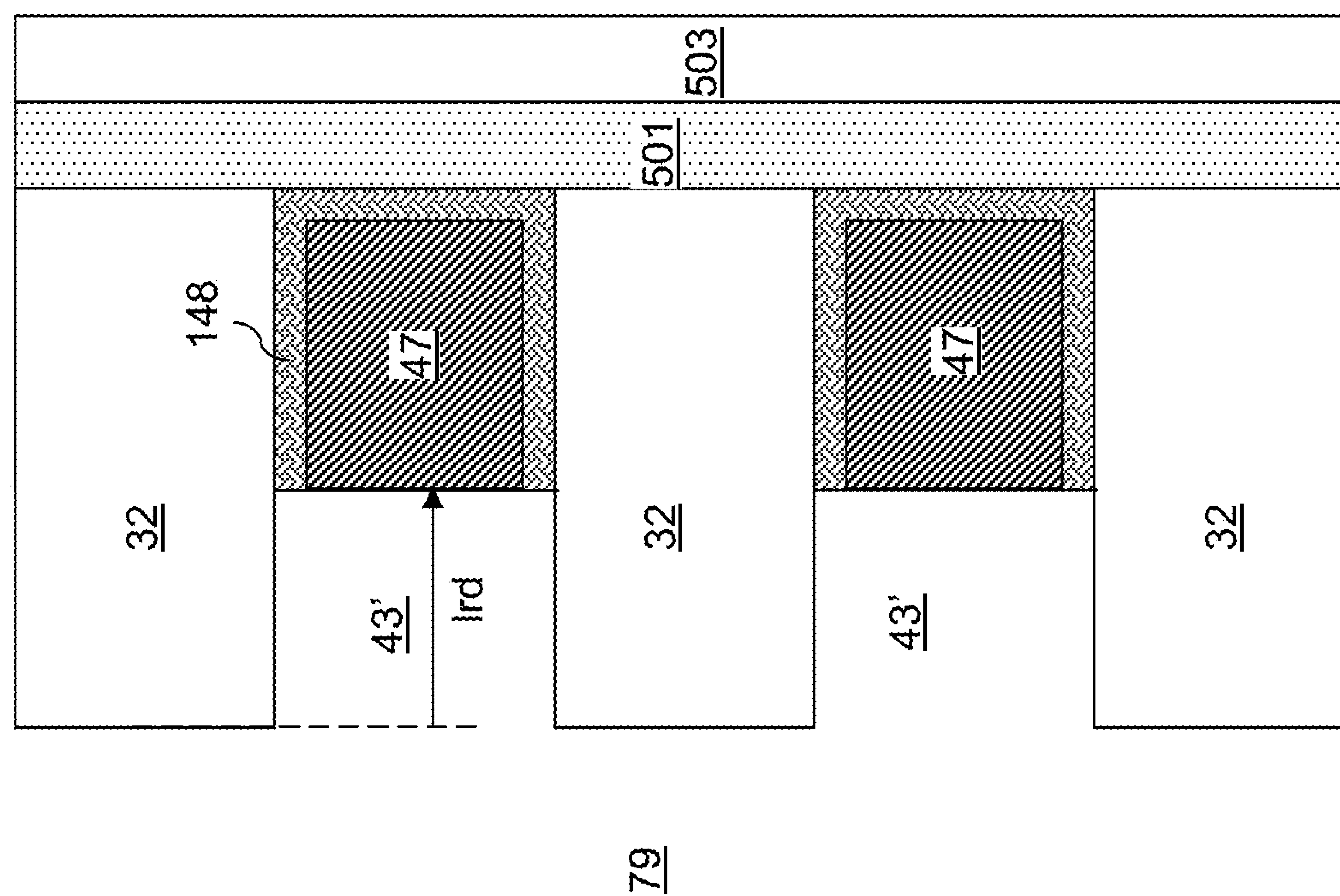

FIG. 22A

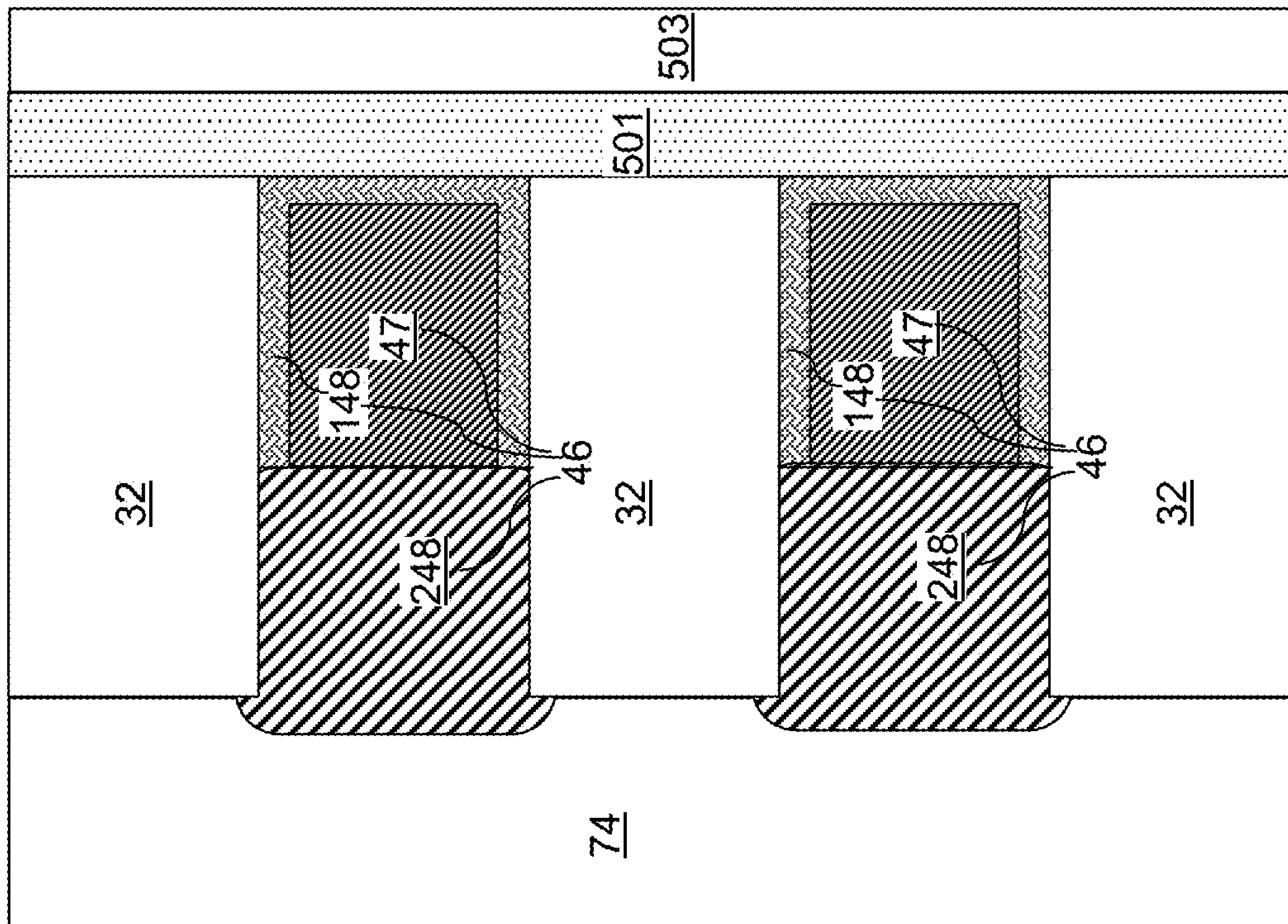

FIG. 22C

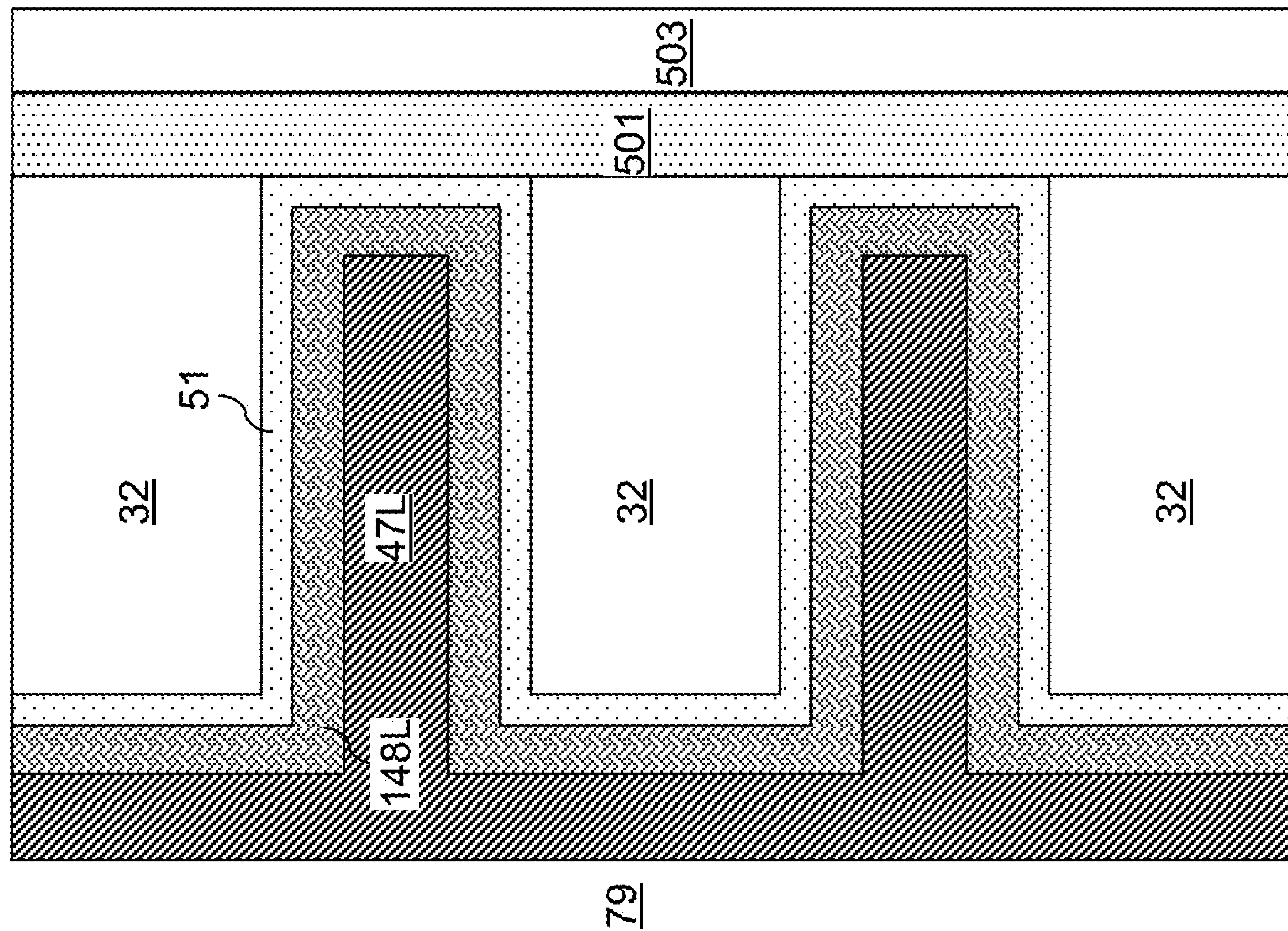

FIG. 23B

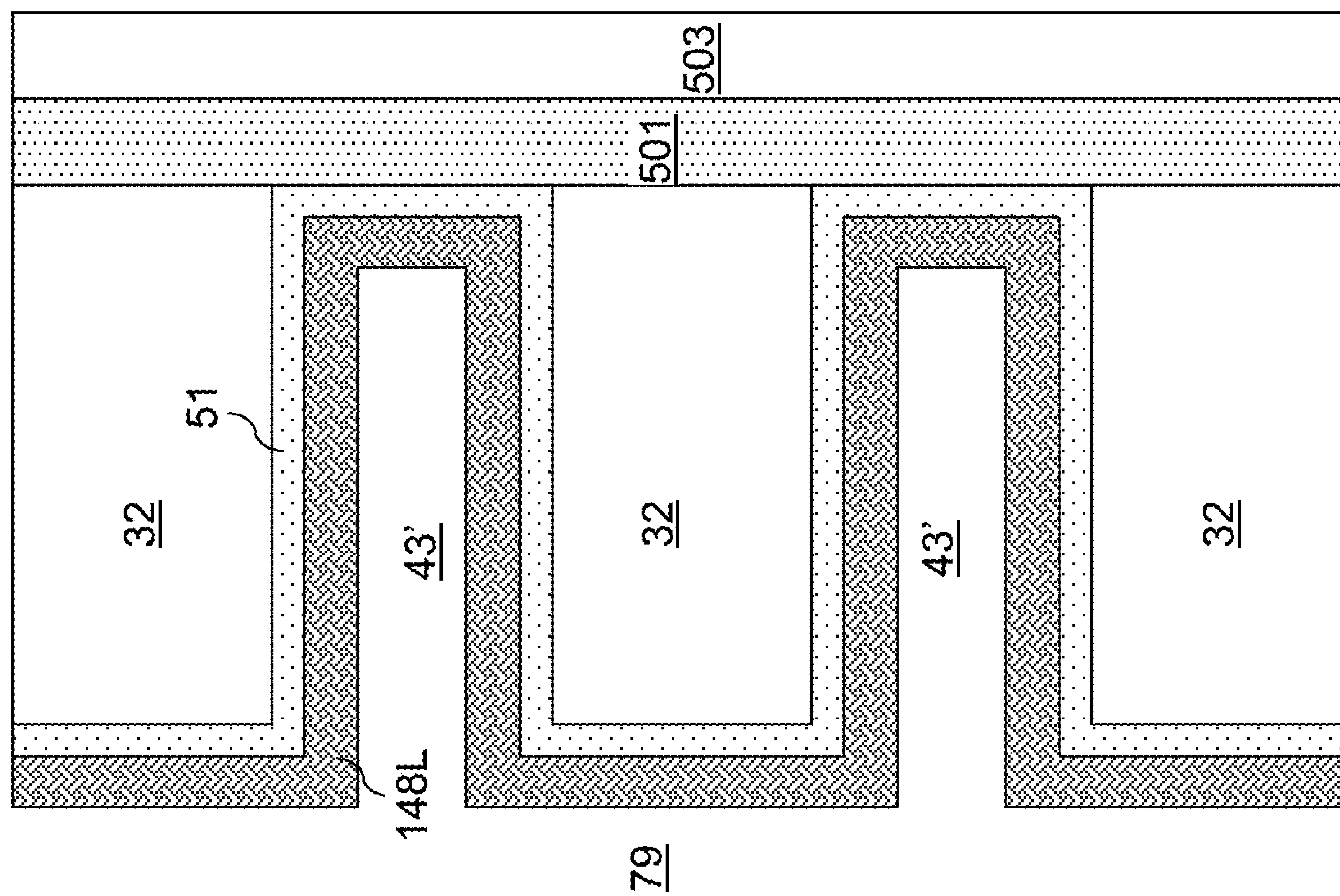

FIG. 23A

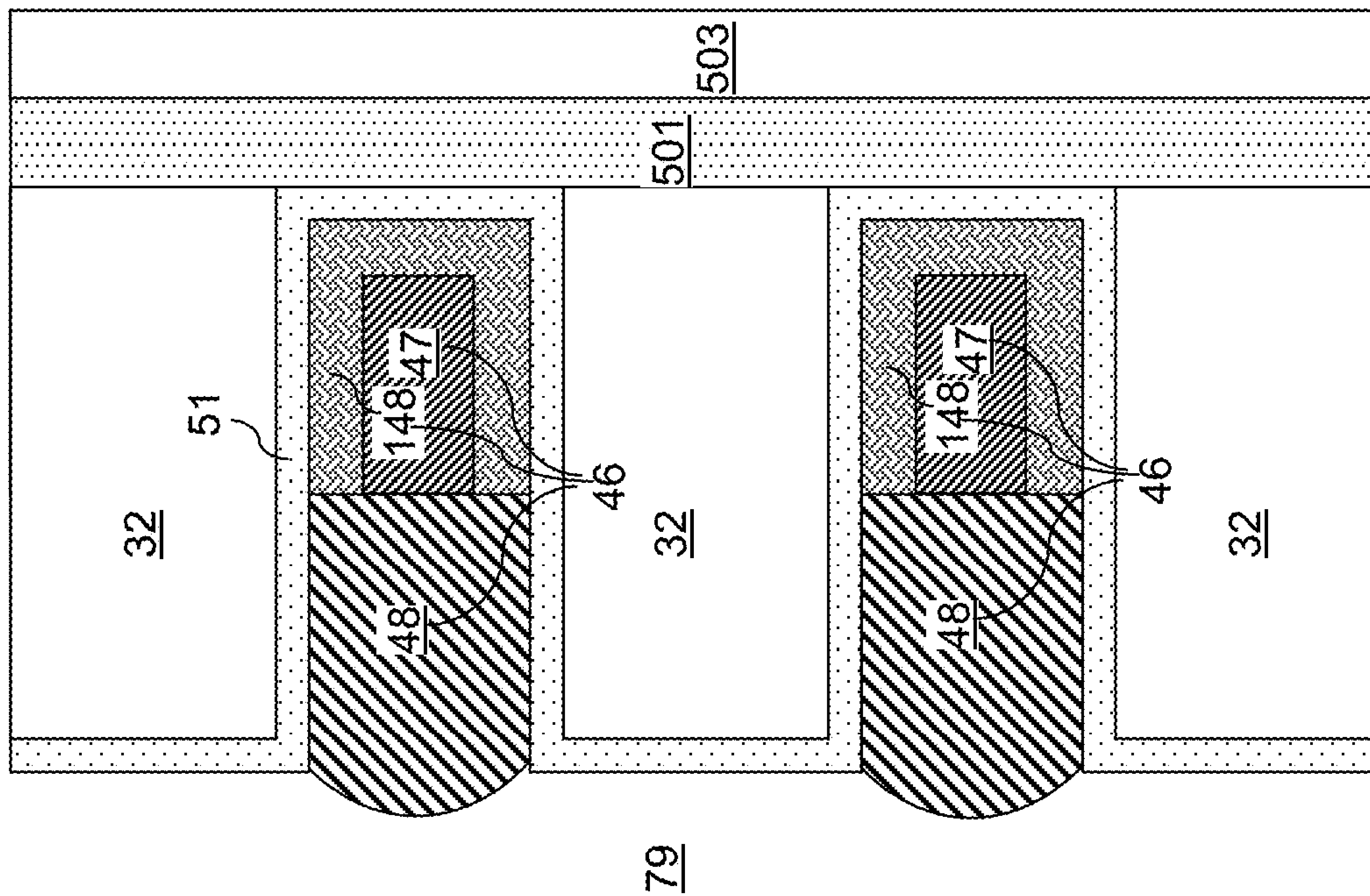

FIG. 23D

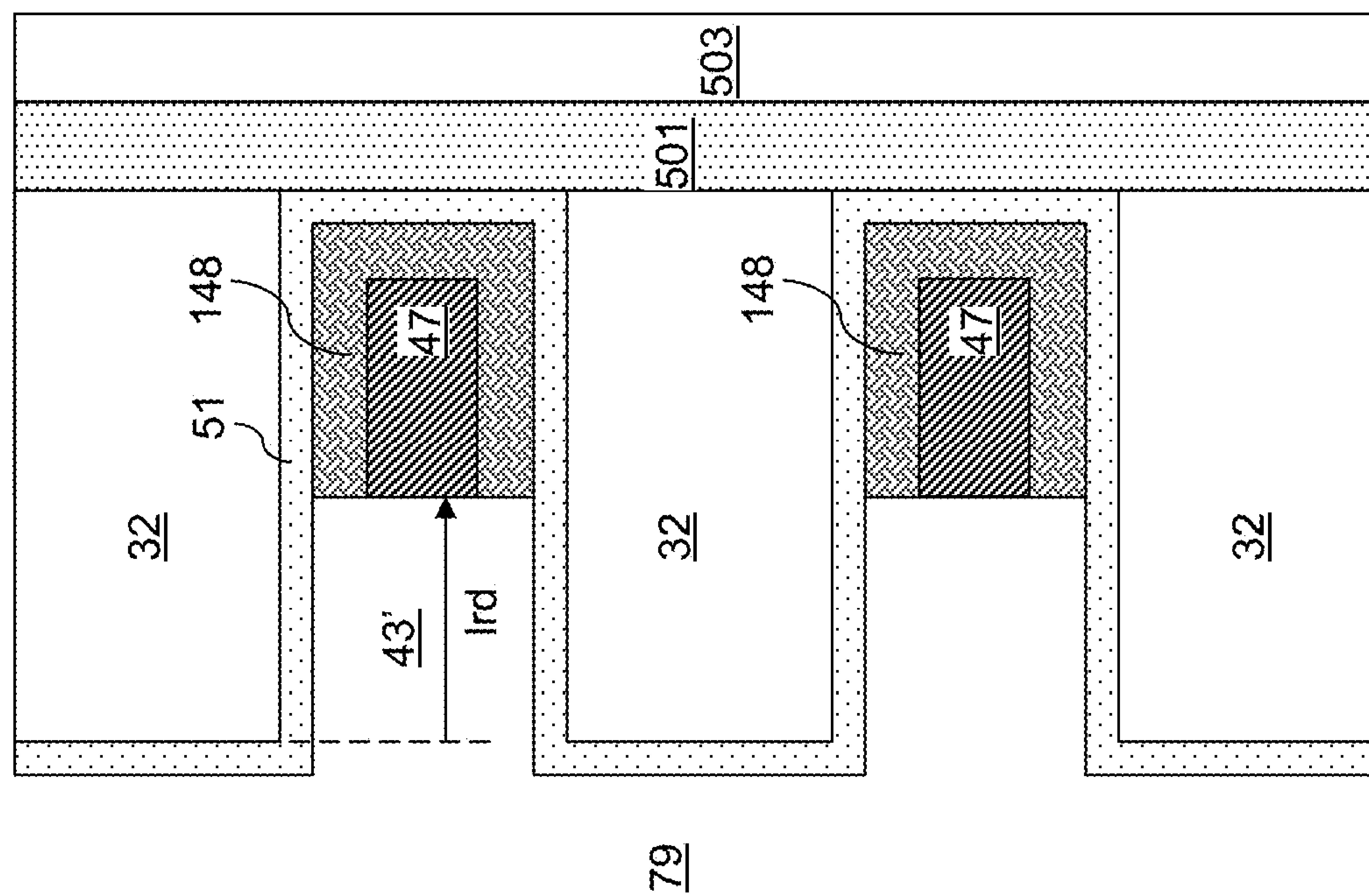

FIG. 23C

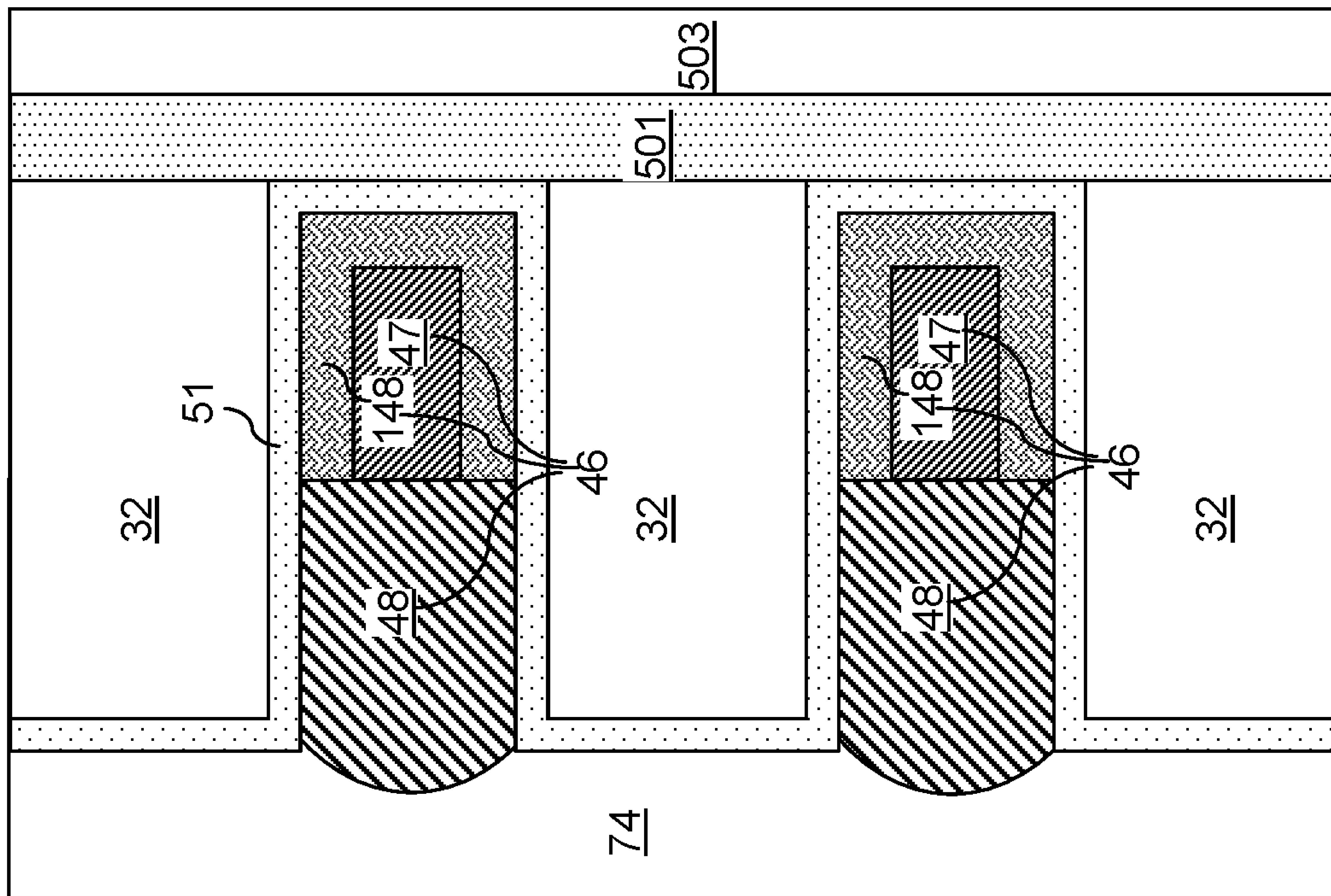

FIG. 23E

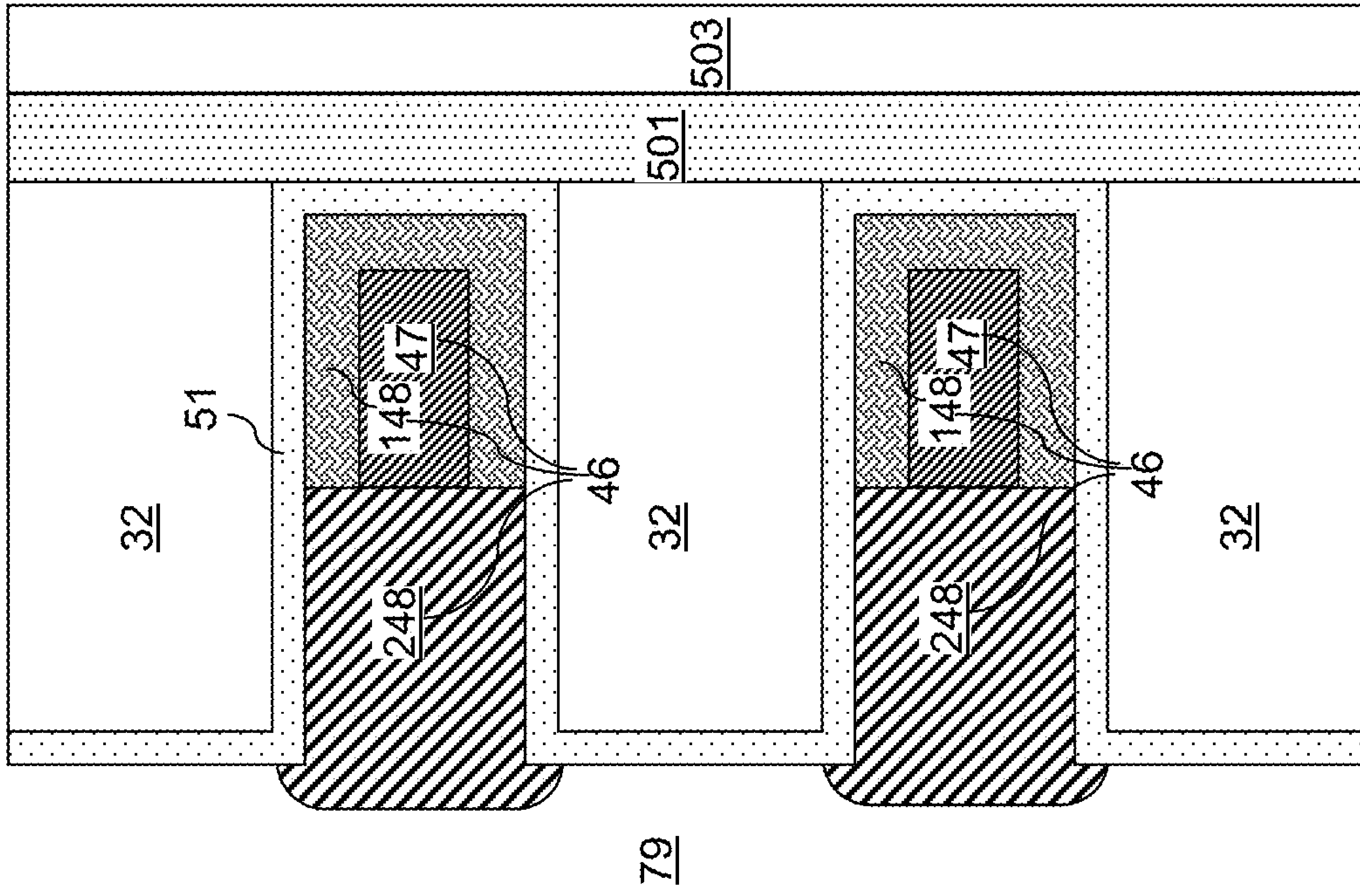

FIG. 24B

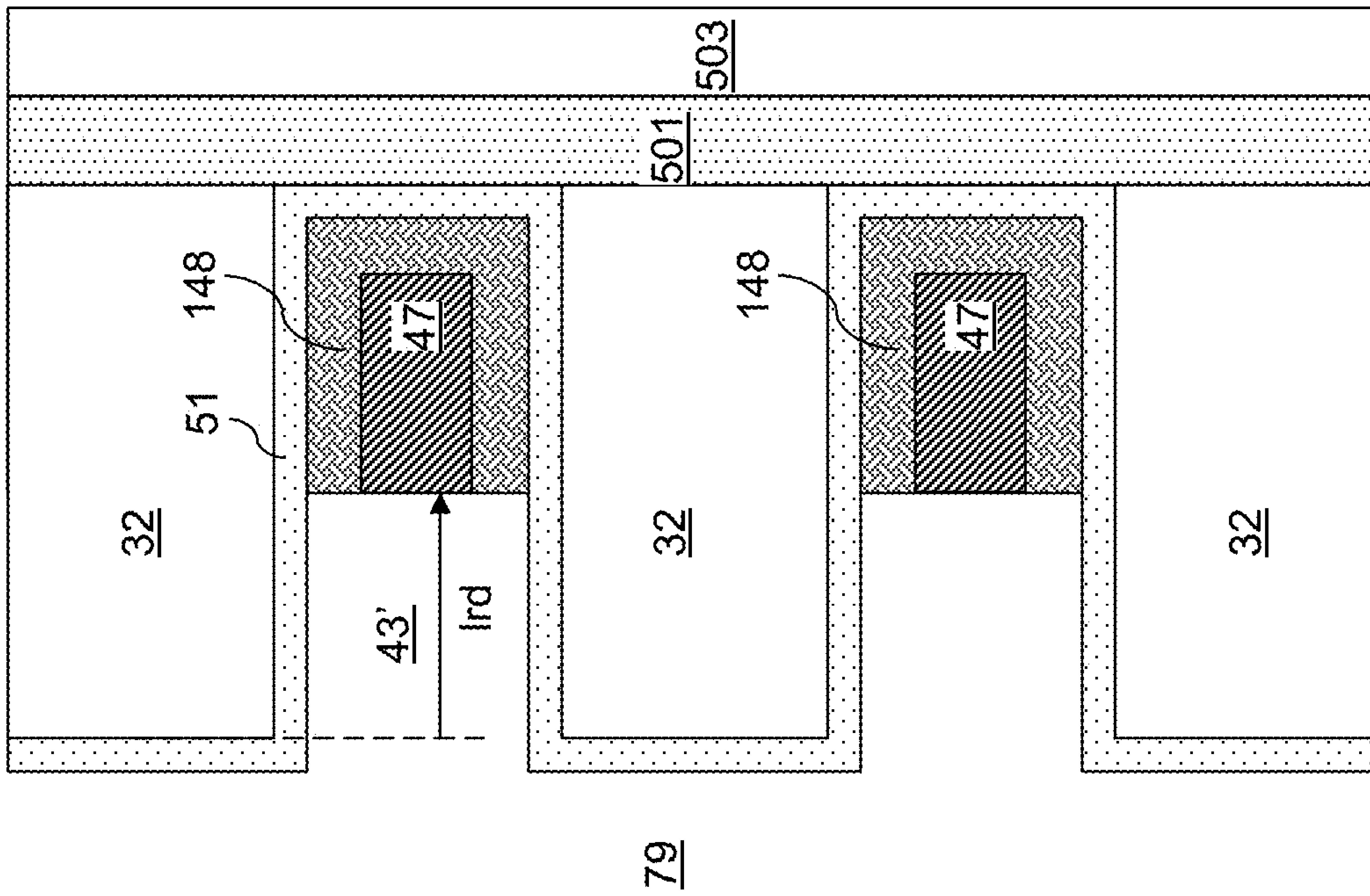

FIG. 24A

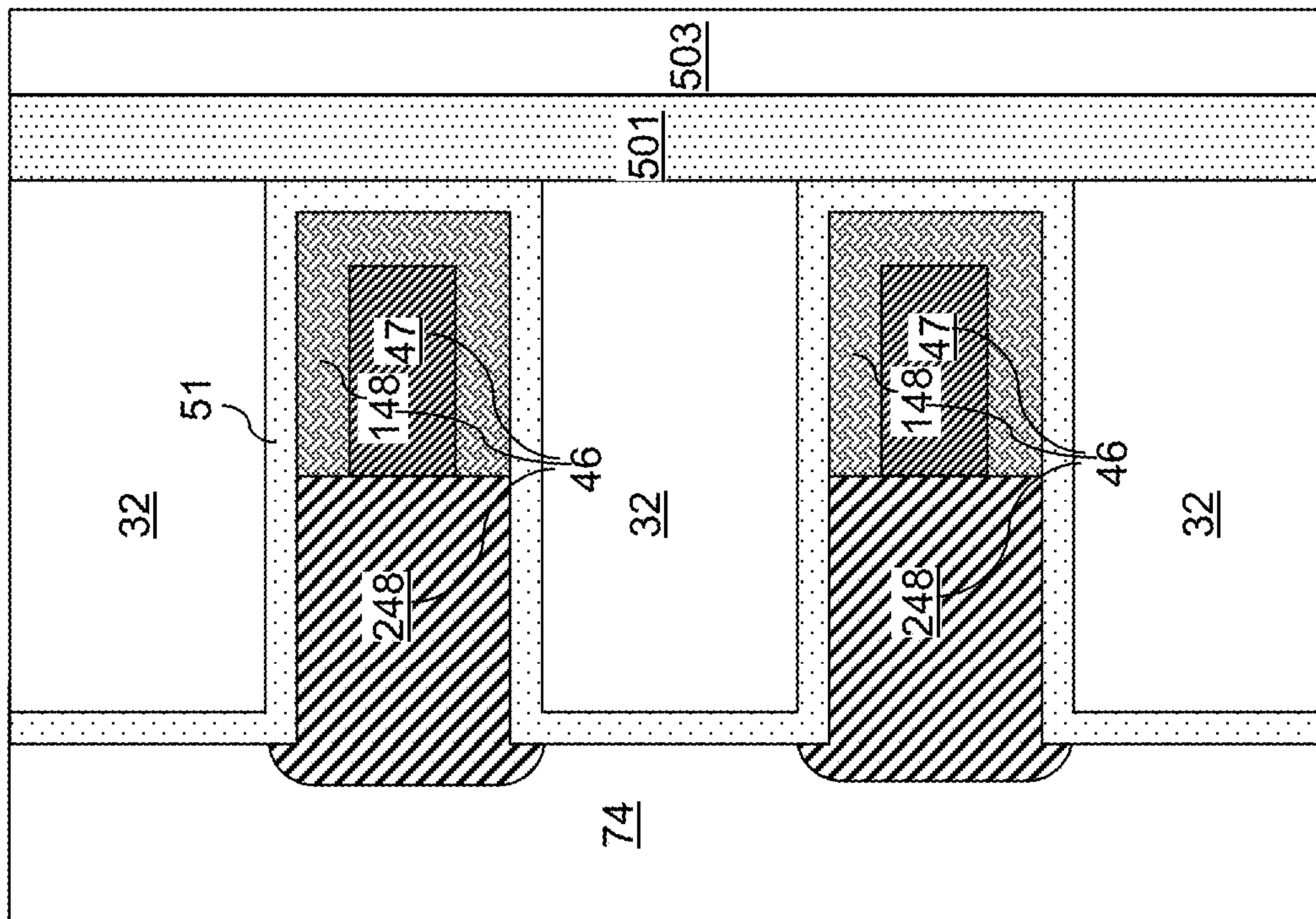

FIG. 24C

THREE-DIMENSIONAL MEMORY DEVICE HAVING MULTILAYER WORD LINES CONTAINING SELECTIVELY GROWN COBALT OR RUTHENIUM AND METHOD OF MAKING THE SAME

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. application Ser. No. 15/223,729 filed on Jul. 29, 2016, which is a continuation-in-part of U.S. application Ser. No. 14/613,956, filed Feb. 4, 2015. Further, the present application claims the benefit of priority of U.S. Provisional Patent Application Ser. No. 62/478,272 filed on Mar. 29, 2017. All of the priority applications are incorporated herein by reference in their entirety.

FIELD

The present disclosure relates generally to the field of semiconductor devices and specifically to three-dimensional memory structures, such as vertical NAND strings and other three-dimensional devices, and methods of making thereof.

BACKGROUND

Three-dimensional vertical NAND strings having one bit per cell are disclosed in an article by T. Endoh et al., titled "Novel Ultra High Density Memory With A Stacked-Surrounding Gate Transistor (S-SGT) Structured Cell", IEDM Proc. (2001) 33-36.

SUMMARY

According to an aspect of the present disclosure, a three-dimensional memory device is provided, which comprises: a stack of alternating layers comprising insulating layers and electrically conductive layers and located over a substrate; a memory opening extending through the alternating stack; and a memory stack structure comprising at least one charge storage structure, a tunneling dielectric, and a vertical semiconductor channel and is located within the memory opening. Each of the electrically conductive layers comprises: a metallic barrier material portion; a metallic material portion that is spaced from the memory stack structure by a vertical portion of the metallic barrier material portion, and spaced from the insulating layers by horizontal portions of the metallic barrier material portion; and a metal portion contacting a sidewall of the metallic barrier material portion and a sidewall of the metallic material portion and an overlying insulating surface and an underlying insulating surface, and comprising a material selected from cobalt and ruthenium.

According to another aspect of the present disclosure, a method of manufacturing a three-dimensional memory device is provided, which comprises the steps of: forming a stack of alternating layers comprising insulating layers and sacrificial material layers over a substrate; forming a memory opening through the stack; forming a memory stack structure comprising at least one charge storage structure, a tunneling dielectric, and a vertical semiconductor channel within the memory opening; forming backside recesses by removing the sacrificial material layers; and forming electrically conductive layers within the backside recesses. Each of the electrically conductive layers is formed by: forming a metallic barrier material portion; forming a metallic material portion, wherein the metallic material portion is spaced from the memory stack structure by a vertical portion of the metallic barrier material portion, and spaced from the insulating layers by horizontal portions of the metallic barrier material portion; and selectively forming a metal portion comprising a material selected from cobalt and ruthenium directly on a sidewall of the metallic barrier material portion and a sidewall of the metallic material portion and an overlying insulating surface and an underlying insulating surface.

According to an aspect of the present disclosure, a three-dimensional memory device is provided, which comprises: a stack of alternating layers comprising insulating layers and electrically conductive layers and located over a substrate; a memory opening extending through the alternating stack; and a memory stack structure comprising at least one charge storage structure, a tunneling dielectric, and a vertical semiconductor channel and is located within the memory opening. Each of the electrically conductive layers comprises at least a cobalt portion.

According to another aspect of the present disclosure, a method of manufacturing a three-dimensional memory device is provided. A stack of alternating layers comprising insulating layers and sacrificial material layers is formed over a substrate. A memory opening is formed through the stack. A memory stack structure comprising at least one charge storage structure, a tunneling dielectric, and a vertical semiconductor channel is formed within the memory opening. Backside recesses are formed around the blocking dielectric by removing the sacrificial material layers. Electrically conductive layers are formed within the backside recesses. Each of the electrically conductive layers is formed by forming at least a cobalt portion within a respective backside recess.

According to an aspect of the present disclosure, a three-dimensional memory device is provided, which comprises a stack of alternating layers comprising insulating layers and electrically conductive layers and located over a substrate, a memory opening extending through the alternating stack, and a memory film and a semiconductor channel located within the memory opening. Each of the electrically conductive layers comprises a cobalt portion.

According to an aspect of the present disclosure, a three-dimensional memory device is provided, which comprises a stack of alternating layers comprising insulating layers and electrically conductive layers and located over a substrate, an opening extending through the alternating stack, a blocking dielectric, at least one charge storage structure and a tunneling dielectric located within the opening, and a semiconductor channel located within the opening. Each of the electrically conductive layers comprises at least a cobalt portion.

According to another aspect of the present disclosure, a method of manufacturing a three-dimensional memory device is provided. A stack of alternating layers comprising insulating layers and sacrificial material layers is formed over a substrate. A memory opening is formed through the stack. A memory film and a semiconductor channel are formed in the memory opening. Backside recesses are formed around the memory film by removing the sacrificial material layers. Electrically conductive layers are formed within the backside recesses. Each of the electrically conductive layers is formed by forming at least a cobalt portion within a respective backside recess.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical cross-sectional view of an exemplary structure after formation of a stack including an alternating

plurality of material layers and memory openings extending through the alternating stack according to an embodiment of the present disclosure.

FIGS. **2**A-**2**F are sequential vertical cross-sectional views of a memory opening within the exemplary structure during various processing steps employed to form a memory stack structure according to an embodiment of the present disclosure.

FIG. **3** is a vertical cross-sectional view of the exemplary structure after formation of memory stack structures according to an embodiment of the present disclosure.

FIG. **4** is a vertical cross-sectional view of the exemplary structure after formation of a set of stepped surfaces and a retro-stepped dielectric material portion according to an embodiment of the present disclosure.

FIG. **5**A is a vertical cross-sectional view of the exemplary structure after formation of a backside via cavity and backside recesses according to an embodiment of the present disclosure.

FIG. **5**B is a see-through top-down view of the exemplary structure of FIG. **5**A. The vertical plane A-A' is the plane of the vertical cross-sectional view of FIG. **5**A.

FIGS. **6**A-**6**D are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of first exemplary electrically conductive layers according to a first embodiment of the present disclosure.

FIGS. **7**A and **7**B are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of second exemplary electrically conductive layers according to a second embodiment of the present disclosure.

FIGS. **8**A-**8**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of third exemplary electrically conductive layers according to a third embodiment of the present disclosure.

FIGS. **9**A-**9**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of fourth exemplary electrically conductive layers according to a fourth embodiment of the present disclosure.

FIGS. **10**A and **10**B are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of fifth exemplary electrically conductive layers according to a fifth embodiment of the present disclosure.

FIGS. **11**A-**11**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of sixth exemplary electrically conductive layers according to a sixth embodiment of the present disclosure.

FIGS. **12**A-**12**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of seventh exemplary electrically conductive layers according to a seventh embodiment of the present disclosure.

FIGS. **13**A and **13**B are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of eighth exemplary electrically conductive layers according to an eighth embodiment of the present disclosure.

FIGS. **14**A-**14**E are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of ninth exemplary electrically conductive layers according to a ninth embodiment of the present disclosure.

FIG. **15** is a vertical cross-sectional view of the exemplary structure after formation of electrically conductive lines according to an embodiment of the present disclosure.

FIG. **16** is a vertical cross-sectional view of the exemplary structure after formation of a backside via space and a backside contact via structure according to an embodiment of the present disclosure.

FIGS. **17**A and **17**B are vertical cross-sectional views of regions of the exemplary structure after formation of conductive line structures according to an embodiment of the present disclosure.

FIGS. **18**A-**18**F are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of tenth exemplary electrically conductive layers according to an embodiment of the present disclosure.

FIGS. **19**A-**19**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of eleventh exemplary electrically conductive layers according to an embodiment of the present disclosure.

FIG. **19**D is a vertical cross-sectional view of a magnified region M in FIGS. **5**A and **5**B after formation of an alternate embodiment of the eleventh exemplary electrically conductive layers according to an embodiment of the present disclosure.

FIGS. **20**A-**20**C are vertical cross-sectional views of modifications of the exemplary structure of FIG. **18**F according to embodiments of the present disclosure.

FIGS. **21**A-**21**C are sequential vertical cross-sectional views of modifications of the exemplary structure of FIG. **19**D according to an embodiment of the present disclosure.

FIGS. **22**A-**22**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during formation of twelfth exemplary electrically conductive layers according to an embodiment of the present disclosure.

FIGS. **23**A-**23**E are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during, and after, formation of thirteenth exemplary electrically conductive layers according to an embodiment of the present disclosure.

FIGS. **24**A-**24**C are sequential vertical cross-sectional views of a magnified region M in FIGS. **5**A and **5**B during, and after, formation of fourteenth exemplary electrically conductive layers according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

As discussed above, the present disclosure is directed to three-dimensional memory structures, such as vertical NAND strings and other three-dimensional devices, and methods of making thereof, the various aspects of which are described below. The embodiments of the disclosure can be employed to form various structures including a multilevel memory structure, non-limiting examples of which include semiconductor devices such as three-dimensional monolithic memory array devices comprising a plurality of NAND memory strings. The drawings are not drawn to scale. Multiple instances of an element may be duplicated where a single instance of the element is illustrated, unless absence of duplication of elements is expressly described or clearly indicated otherwise. Ordinals such as "first," "second," and "third" are employed merely to identify similar elements, and different ordinals may be employed across the specification and the claims of the instant disclosure. As used herein, a first element located "on" a second element can be located on the exterior side of a surface of the second element or on the interior side of the second element. As used herein, a first element is located "directly on" a second element if there exist a physical contact between a surface of the first element and a surface of the second element.

A monolithic three-dimensional memory array is one in which multiple memory levels are formed above a single substrate, such as a semiconductor wafer, with no intervening substrates. The term "monolithic" means that layers of each level of the array are directly deposited on the layers of each underlying level of the array. In contrast, two-dimensional arrays may be formed separately and then packaged together to form a non-monolithic memory device. For example, non-monolithic stacked memories have been constructed by forming memory levels on separate substrates and vertically stacking the memory levels, as described in U.S. Pat. No. 5,915,167 titled "Three-dimensional Structure Memory." The substrates may be thinned or removed from the memory levels before bonding, but as the memory levels are initially formed over separate substrates, such memories are not true monolithic three-dimensional memory arrays. The various three-dimensional memory devices of the present disclosure include a monolithic three-dimensional NAND string memory device, and can be fabricated employing the various embodiments described herein.

Tungsten is widely employed for the material of conductive metal lines. The inventors of the present disclosure recognized that high tensile stress generated by tungsten can generate warpage of a device structure. Further, the inventors of the present disclosure recognized that cobalt is a softer metal than tungsten, and may be deposited employing a thinner metallic barrier material layer than a metallic barrier metal layer required for tungsten deposition. Use of a thinner metallic barrier material layer for cobalt deposition relative to tungsten deposition is possible because cobalt can be deposited employing precursor gases that do not contain fluorine. For example, bis(cyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, or bis(pentamethylcyclopentadienyl)cobalt may be employed to deposit cobalt. In addition, cobalt has a bulk resistivity of 6.24 μOhm-cm, which is comparable with the bulk resistivity of tungsten of 5.28 μOhm-cm. As the thickness of conductive metal layers decreases, therefore, it is possible to provide a metal interconnect structure having a lesser or comparable total resistance employing a combination of a thinner metallic barrier layer and a cobalt portion than a combination of a thicker metallic barrier layer and a tungsten portion.

Referring to FIG. **1**, an exemplary structure according to an embodiment of the present disclosure is illustrated, which can be employed, for example, to fabricate a device structure containing vertical NAND memory devices. The exemplary structure includes a substrate, which can be a semiconductor substrate. The substrate can include a substrate semiconductor layer **9**. The substrate semiconductor layer **9** is a semiconductor material layer, and can include at least one elemental semiconductor material, at least one III-V compound semiconductor material, at least one II-VI compound semiconductor material, at least one organic semiconductor material, or other semiconductor materials known in the art. The substrate can have a major surface **7**, which can be, for example, a topmost surface of the substrate semiconductor layer **9**. The major surface **7** can be a semiconductor surface. In one embodiment, the major surface **7** can be a single crystalline semiconductor surface.

As used herein, a "semiconductor material" refers to a material having electrical conductivity in the range from 1.0×10^{-6} S/cm to 1.0×10^{5} S/cm, and is capable of producing a doped material having electrical resistivity in a range from 1.0 S/cm to 1.0×10^{5} S/cm upon suitable doping with an electrical dopant. As used herein, an "electrical dopant" refers to a p-type dopant that adds a hole to a valence band within a band structure, or an n-type dopant that adds an electron to a conduction band within a band structure. As used herein, a "conductive material" refers to a material having electrical conductivity greater than 1.0×10^{5} S/cm. As used herein, an "insulator material", "insulating material" or a "dielectric material" refers to a material having electrical conductivity less than 1.0×10^{-6} S/cm. All measurements for electrical conductivities are made at the standard condition. Optionally, at least one doped well (not expressly shown) can be formed within the substrate semiconductor layer **9**.

At least one semiconductor device for a peripheral circuitry can be formed on a portion of the substrate semiconductor layer **9**. The at least one semiconductor device can include, for example, field effect transistors. For example, at least one shallow trench isolation structure **120** can be formed by etching portions of the substrate semiconductor layer **9** and depositing a dielectric material therein. A gate dielectric layer, at least one gate conductor layer, and a gate cap dielectric layer can be formed over the substrate semiconductor layer **9**, and can be subsequently patterned to form at least one gate structure (**150**, **152**, **154**, **158**), each of which can include a gate dielectric **150**, at least one gate electrode (**152**, **154**), and a gate cap dielectric. A gate electrode (**152**, **154**) may include a stack of a first gate electrode portion **152** and a second gate electrode portion **154**. At least one gate spacer **156** can be formed around the at least one gate structure (**150**, **152**, **154**, **158**) by depositing and anisotropically etching a conformal dielectric layer. Active regions **130** can be formed in upper portions of the substrate semiconductor layer **9**, for example, by introducing electrical dopants employing the at least one gate structure (**150**, **152**, **154**, **158**) as masking structures. Additional masks may be employed as needed. The active region **130** can include source regions and drain regions of field effect transistors. A first dielectric liner **161** and a second dielectric liner **162** can be optionally formed. Each of the first and second dielectric liners (**161**, **162**) can comprise a silicon oxide layer, a silicon nitride layer, and/or a dielectric metal oxide layer. In an illustrative example, the first dielectric liner **161** can be a silicon oxide layer, and the second dielectric liner **162** can be a silicon nitride layer. The least one semiconductor device for the peripheral circuitry can contain a driver circuit for memory devices to be subsequently formed, which can include at least one NAND device.

A dielectric material such as silicon oxide can be deposited over the at least one semiconductor device, and can be subsequently planarized to form a planarization dielectric layer **170**. In one embodiment the planarized top surface of the planarization dielectric layer **170** can be coplanar with a top surface of the dielectric liners (**161**, **162**). Subsequently, the planarization dielectric layer **170** and the dielectric liners (**161**, **162**) can be removed from an area to physically expose a top surface of the substrate semiconductor layer **9**.

An optional semiconductor material layer **10** can be formed on the top surface of the substrate semiconductor layer **9** by deposition of a single crystalline semiconductor material, for example, by selective epitaxy. The deposited semiconductor material can be the same as, or can be different from, the semiconductor material of the substrate semiconductor layer **9**. The deposited semiconductor material can be any material that can be employed for the semiconductor substrate layer **9** as described above. The single crystalline semiconductor material of the semiconductor material layer **10** can be in epitaxial alignment with the single crystalline structure of the substrate semiconductor layer **9**. Portions of the deposited semiconductor material

located above the top surface of the planarization dielectric layer **70** can be removed, for example, by chemical mechanical planarization (CMP). In this case, the semiconductor material layer **10** can have a top surface that is coplanar with the top surface of the planarization dielectric layer **170**.

Optionally, a dielectric pad layer **12** can be formed above the semiconductor material layer **10** and the planarization dielectric layer **170**. The dielectric pad layer **12** can be, for example, silicon oxide layer. The thickness of the dielectric pad layer **12** can be in a range from 3 nm to 30 nm, although lesser and greater thicknesses can also be employed.

At least one optional shallow trench can be formed through the dielectric pad layer **12** and an upper portion of the semiconductor material layer **10**. The pattern of the at least one shallow trench can be selected such that lower select gate electrodes can be subsequently formed therein. For example, a lower select gate device level may be fabricated as described in U.S. patent application Ser. No. 14/133,979, filed on Dec. 19, 2013, U.S. patent application Ser. No. 14/225,116, filed on Mar. 25, 2014, and/or U.S. patent application Ser. No. 14/225,176, filed on Mar. 25, 2014, all of which are incorporated herein by reference.

A lower select gate structure **20** can be formed in each of the at least one shallow trench, for example, by forming a gate dielectric layer and at least one conductive material layer, and removing portions of the gate dielectric layer and the at least one conductive material layer from above the top surface of the dielectric pad layer **12**, for example, by chemical mechanical planarization. Each lower select gate structure **20** can include a gate dielectric **22** and a gate electrode (**24**, **26**). In one embodiment, each gate electrode (**24**, **26**) can include an electrically conductive liner **24** and a conductive material portion **26**. The electrically conductive liner **24** can include, for example, TiN, TaN, WN, or a combination thereof. The conductive material portion **26** can include, for example, W, Al, Cu, or combinations thereof. At least one optional shallow trench isolation structure (not shown) and/or at least one deep trench isolation structure (not shown) may be employed to provide electrical isolation among various semiconductor devices that are present, or are to be subsequently formed, on the substrate.

A dielectric cap layer **31** can be optionally formed. The dielectric cap layer **31** includes a dielectric material, and can be formed directly on top surfaces of the gate electrodes (**24**, **26**). Exemplary materials that can be employed for the dielectric cap layer **31** include, but are not limited to, silicon oxide, a dielectric metal oxide, and silicon nitride (in case the material of second material layers to be subsequently formed is not silicon nitride). The dielectric cap layer **31** provides electrical isolation for the gate electrodes (**24**, **26**).

A stack of an alternating plurality of first material layers (which can be insulating layers **32**) and second material layers (which can be sacrificial material layer **42**) is formed over the top surface of the substrate, which can be, for example, on the top surface of the dielectric cap layer **31**. As used herein, an alternating plurality of first elements and second elements refers to a structure in which instances of the first elements and instances of the second elements alternate. Each instance of the first elements that is not an end element of the alternating plurality is adjoined by two instances of the second elements on both sides, and each instance of the second elements that is not an end element of the alternating plurality is adjoined by two instances of the first elements on both ends. The first elements may have the same thickness thereamongst, or may have different thicknesses. The second elements may have the same thickness thereamongst, or may have different thicknesses. The alternating plurality of first material layers and second material layers may begin with an instance of the first material layers or with an instance of the second material layers, and may end with an instance of the first material layers or with an instance of the second material layers. In one embodiment, an instance of the first elements and an instance of the second elements may form a unit that is repeated with periodicity within the alternating plurality.

Each first material layer includes a first material, and each second material layer includes a second material that is different from the first material. In one embodiment, each first material layer can be an insulating layer (i.e., insulator layer) **32**, and each second material layer can be a sacrificial material layer. In this case, the stack can include an alternating plurality of insulating layers **32** and sacrificial material layers **42**.

The stack of the alternating plurality is herein referred to as an alternating stack (**32**, **42**). In one embodiment, the alternating stack (**32**, **42**) can include insulating layers **32** composed of the first material, and sacrificial material layers **42** composed of a second material different from that of insulating layers **32**. The first material of the insulating layers **32** can be at least one electrically insulating material. As such, each insulating layer **32** can be an electrically insulating material layer. Electrically insulating materials that can be employed for the insulating layers **32** include, but are not limited to, silicon oxide (including doped or undoped silicate glass), silicon nitride, silicon oxynitride, organosilicate glass (OSG), spin-on dielectric materials, dielectric metal oxides that are commonly known as high dielectric constant (high-k) dielectric oxides (e.g., aluminum oxide, hafnium oxide, etc.) and silicates thereof, dielectric metal oxynitrides and silicates thereof, and organic insulating materials. In one embodiment, the first material of the insulating layers **32** can be silicon oxide.

The second material of the sacrificial material layers **42** is a sacrificial material that can be removed selective to the first material of the insulating layers **32**. As used herein, a removal of a first material is "selective to" a second material if the removal process removes the first material at a rate that is at least twice the rate of removal of the second material. The ratio of the rate of removal of the first material to the rate of removal of the second material is herein referred to as a "selectivity" of the removal process for the first material with respect to the second material.

The sacrificial material layers **42** may comprise an electrically insulating material, a semiconductor material, or a conductive material. The second material of the sacrificial material layers **42** can be subsequently replaced with electrically conductive electrodes, which can function, for example, as control gate electrodes of a vertical NAND device. Non-limiting examples of the second material include silicon nitride, an amorphous semiconductor material (such as amorphous silicon), and a polycrystalline semiconductor material (such as polysilicon). In one embodiment, the sacrificial material layers **42** can be material layers that comprise silicon nitride or a semiconductor material including at least one of silicon and germanium.

In one embodiment, the insulating layers **32** can include silicon oxide, and sacrificial material layers can include silicon nitride sacrificial material layers. The first material of the insulating layers **32** can be deposited, for example, by chemical vapor deposition (CVD). For example, if silicon oxide is employed for the insulating layers **32**, tetraethyl orthosilicate (TEOS) can be employed as the precursor material for the CVD process. The second material of the

sacrificial material layers **42** can be formed, for example, CVD or atomic layer deposition (ALD).

The sacrificial material layers **42** can be suitably patterned so that conductive material portions to be subsequently formed by replacement of the sacrificial material layers **42** can function as electrically conductive electrodes, such as the control gate electrodes of the monolithic three-dimensional NAND string memory devices to be subsequently formed. The sacrificial material layers **42** may comprise a portion having a strip shape extending substantially parallel to the major surface **7** of the substrate.

The thicknesses of the insulating layers **32** and the sacrificial material layers **42** can be in a range from 20 nm to 50 nm, although lesser and greater thicknesses can be employed for each insulating layer **32** and for each sacrificial material layer **42**. The number of repetitions of the pairs of an insulating layer **32** and a sacrificial material layer (e.g., a control gate electrode or a sacrificial material layer) **42** can be in a range from 2 to 1,024, and typically from 8 to 256, although a greater number of repetitions can also be employed. The top and bottom gate electrodes in the stack may function as the select gate electrodes. In one embodiment, each sacrificial material layer **42** in the alternating stack (**32**, **42**) can have a uniform thickness that is substantially invariant within each respective sacrificial material layer **42**.

Optionally, an insulating cap layer **70** can be formed over the alternating stack (**32**, **42**). The insulating cap layer **70** includes a dielectric material that is different from the material of the sacrificial material layers **42**. In one embodiment, the insulating cap layer **70** can include a dielectric material that can be employed for the insulating layers **32** as described above. The insulating cap layer **70** can have a greater thickness than each of the insulating layers **32**. The insulating cap layer **70** can be deposited, for example, by chemical vapor deposition. In one embodiment, the insulating cap layer **70** can be a silicon oxide layer.

Subsequently, a lithographic material stack (not shown) including at least a photoresist layer can be formed over the insulating cap layer **70** and the alternating stack (**32**, **42**), and can be lithographically patterned to form openings therein. The pattern in the lithographic material stack can be transferred through the insulating cap layer **70** and through entirety of the alternating stack (**32**, **42**) by at least one anisotropic etch that employs the patterned lithographic material stack as an etch mask. Portions of the alternating stack (**32**, **42**) underlying the openings in the patterned lithographic material stack are etched to form memory openings **49**. In other words, the transfer of the pattern in the patterned lithographic material stack through the alternating stack (**32**, **42**) forms the memory openings **49** that extend through the alternating stack (**32**, **42**). The chemistry of the anisotropic etch process employed to etch through the materials of the alternating stack (**32**, **42**) can alternate to optimize etching of the first and second materials in the alternating stack (**32**, **42**). The anisotropic etch can be, for example, a series of reactive ion etches. Optionally, the dielectric cap layer **31** may be used as an etch stop layer between the alternating stack (**32**, **42**) and the substrate. The sidewalls of the memory openings **49** can be substantially vertical, or can be tapered. The patterned lithographic material stack can be subsequently removed, for example, by ashing.

The memory openings **49** are formed through the dielectric cap layer **31** and the dielectric pad layer **12** so that the memory openings **49** extend from the top surface of the alternating stack (**32**, **42**) to the top surface of the semiconductor material layer **10** within the substrate between the lower select gate electrodes (**24**, **26**). In one embodiment, an overetch into the semiconductor material layer **10** may be optionally performed after the top surface of the semiconductor material layer **10** is physically exposed at a bottom of each memory opening **49**. The overetch may be performed prior to, or after, removal of the lithographic material stack. In other words, the recessed surfaces of the semiconductor material layer **10** may be vertically offset from the unrecessed top surfaces of the semiconductor material layer **10** by a recess depth. The recess depth can be, for example, in a range from 1 nm to 50 nm, although lesser and greater recess depths can also be employed. The overetch is optional, and may be omitted. If the overetch is not performed, the bottom surface of each memory opening **49** can be coplanar with the topmost surface of the semiconductor material layer **10**. Each of the memory openings **49** can include a sidewall (or a plurality of sidewalls) that extends substantially perpendicular to the topmost surface of the substrate. The region in which the array of memory openings **49** is formed is herein referred to as a device region. The substrate semiconductor layer **9** and the semiconductor material layer **10** collectively constitutes a substrate (**9**, **10**), which can be a semiconductor substrate. Alternatively, the semiconductor material layer **10** may be omitted, and the memory openings **49** can be extend to a top surface of the semiconductor material layer **10**.

A memory stack structure can be formed in each of the memory opening employing various embodiments of the present disclosure. FIGS. **2**A-**2**F illustrate sequential vertical cross-sectional views of a memory opening within the exemplary structure during formation of an exemplary memory stack structure according to a first embodiment of the present disclosure. Formation of the exemplary memory stack structure can be performed within each of the memory openings **49** in the exemplary structure illustrated in FIG. **1**.

Referring to FIG. **2**A, a memory opening **49** is illustrated. The memory opening **49** extends through the insulating cap layer **70**, the alternating stack (**32**, **42**), the dielectric cap layer **31**, the dielectric pad layer **12**, and optionally into an upper portion of the semiconductor material layer **10**. The recess depth of the bottom surface of each memory opening with respect to the top surface of the semiconductor material layer **10** can be in a range from 0 nm to 30 nm, although greater recess depths can also be employed. Optionally, the sacrificial material layers **42** can be laterally recessed partially to form lateral recesses (not shown), for example, by an isotropic etch.

A series of layers including at least one blocking dielectric layer (**501**L, **503**L), a memory material layer **504**L, a tunneling dielectric layer **505**L, and an optional first semiconductor channel layer **601**L can be sequentially deposited in the memory openings **49**. The at least one blocking dielectric layer (**501**L, **503**L) can include, for example, a first blocking dielectric layer **501**L and a second blocking dielectric layer **503**L.

The first blocking dielectric layer **501**L can be deposited on the sidewalls of each memory opening **49** by a conformal deposition method. The first blocking dielectric layer **501**L includes a dielectric material, which can be a dielectric metal oxide. As used herein, a dielectric metal oxide refers to a dielectric material that includes at least one metallic element and at least oxygen. The dielectric metal oxide may consist essentially of the at least one metallic element and oxygen, or may consist essentially of the at least one metallic element, oxygen, and at least one non-metallic element such as nitrogen. In one embodiment, the first blocking dielectric

layer **501**L can include a dielectric metal oxide having a dielectric constant greater than 7.9, i.e., having a dielectric constant greater than the dielectric constant of silicon nitride.

Non-limiting examples of dielectric metal oxides include aluminum oxide (Al_2O_3), hafnium oxide (HfO_2), lanthanum oxide (LaO_2), yttrium oxide (Y_2O_3), tantalum oxide (Ta_2O_5), silicates thereof, nitrogen-doped compounds thereof, alloys thereof, and stacks thereof. The first blocking dielectric layer **501**L can be deposited, for example, by chemical vapor deposition (CVD), atomic layer deposition (ALD), pulsed laser deposition (PLD), liquid source misted chemical deposition, or a combination thereof. The thickness of the first blocking dielectric layer **501**L can be in a range from 1 nm to 20 nm, although lesser and greater thicknesses can also be employed. The first blocking dielectric layer **501**L can subsequently function as a dielectric material portion that blocks leakage of stored electrical charges to control gate electrodes. In one embodiment, the first blocking dielectric layer **501**L includes aluminum oxide.

The second blocking dielectric layer **503**L can be formed on the first blocking dielectric layer **501**L. The second blocking dielectric layer **503**L can include a dielectric material that is different from the dielectric material of the first blocking dielectric layer **501**L. In one embodiment, the second blocking dielectric layer **503**L can include silicon oxide, a dielectric metal oxide having a different composition than the first blocking dielectric layer **501**L, silicon oxynitride, silicon nitride, or a combination thereof. In one embodiment, the second blocking dielectric layer **503**L can include silicon oxide. The second blocking dielectric layer **503**L can be formed by a conformal deposition method such as low pressure chemical vapor deposition, atomic layer deposition, or a combination thereof. The thickness of the second blocking dielectric layer **503**L can be in a range from 1 nm to 20 nm, although lesser and greater thicknesses can also be employed. Alternatively, the first blocking dielectric layer **501**L and/or the second blocking dielectric layer **503**L can be omitted, and a blocking dielectric layer can be formed after formation of backside recesses on surfaces of memory films to be subsequently formed.

The memory material layer **504**L, the tunneling dielectric layer **505**L, and the optional first semiconductor channel layer **601**L can be sequentially formed. In one embodiment, the memory material layer **504**L can be a charge trapping material including a dielectric charge trapping material, which can be, for example, silicon nitride. Alternatively, the memory material layer **504**L can include a conductive material such as doped polysilicon or a metallic material that is patterned into multiple electrically isolated portions (e.g., floating gates), for example, by being formed within lateral recesses into sacrificial material layers **42**. In one embodiment, the memory material layer **504**L includes a silicon nitride layer.

The memory material layer **504**L can be formed as a single memory material layer of homogeneous composition, or can include a stack of multiple memory material layers. The multiple memory material layers, if employed, can comprise a plurality of spaced-apart floating gate material layers that contain conductive materials (e.g., metal such as tungsten, molybdenum, tantalum, titanium, platinum, ruthenium, and alloys thereof, or a metal silicide such as tungsten silicide, molybdenum silicide, tantalum silicide, titanium silicide, nickel silicide, cobalt silicide, or a combination thereof) and/or semiconductor materials (e.g., polycrystalline or amorphous semiconductor material including at least one elemental semiconductor element or at least one compound semiconductor material). Alternatively or additionally, the memory material layer **504**L may comprise an insulating charge trapping material, such as one or more silicon nitride segments. Alternatively, the memory material layer **504**L may comprise conductive nanoparticles such as metal nanoparticles, which can be, for example, ruthenium nanoparticles. The memory material layer **504**L can be formed, for example, by chemical vapor deposition (CVD), atomic layer deposition (ALD), physical vapor deposition (PVD), or any suitable deposition technique for storing electrical charges therein. The thickness of the memory material layer **504**L can be in a range from 2 nm to 20 nm, although lesser and greater thicknesses can also be employed.

The tunneling dielectric layer **505**L includes a dielectric material through which charge tunneling can be performed under suitable electrical bias conditions. The charge tunneling may be performed through hot-carrier injection or by Fowler-Nordheim tunneling induced charge transfer depending on the mode of operation of the monolithic three-dimensional NAND string memory device to be formed. The tunneling dielectric layer **505**L can include silicon oxide, silicon nitride, silicon oxynitride, dielectric metal oxides (such as aluminum oxide and hafnium oxide), dielectric metal oxynitride, dielectric metal silicates, alloys thereof, and/or combinations thereof. In one embodiment, the tunneling dielectric layer **505**L can include a stack of a first silicon oxide layer, a silicon oxynitride layer, and a second silicon oxide layer, which is commonly known as an ONO stack. In one embodiment, the tunneling dielectric layer **505**L can include a silicon oxide layer that is substantially free of carbon or a silicon oxynitride layer that is substantially free of carbon. The thickness of the tunneling dielectric layer **505**L can be in a range from 2 nm to 20 nm, although lesser and greater thicknesses can also be employed.

The optional first semiconductor channel layer **601**L includes a semiconductor material such as at least one elemental semiconductor material, at least one III-V compound semiconductor material, at least one II-VI compound semiconductor material, at least one organic semiconductor material, or other semiconductor materials known in the art. In one embodiment, the first semiconductor channel layer **601**L includes amorphous silicon or polysilicon. The first semiconductor channel layer **601**L can be formed by a conformal deposition method such as low pressure chemical vapor deposition (LPCVD). The thickness of the first semiconductor channel layer **601**L can be in a range from 2 nm to 10 nm, although lesser and greater thicknesses can also be employed. A cavity **49'** is formed in the volume of each memory opening **49** that is not filled with the deposited material layers (**501**L, **503**L, **504**L, **5051**, **601**L).

Referring to FIG. **2**B, the optional first semiconductor channel layer **601**L, the tunneling dielectric layer **505**L, the memory material layer **504**L, the at least one blocking dielectric layer (**501**L, **503**L) are sequentially anisotropically etched employing at least one anisotropic etch process. The portions of the first semiconductor channel layer **601**L, the tunneling dielectric layer **505**L, the memory material layer **504**L, and the at least one blocking dielectric layer (**501**L, **503**L) located above the top surface of the insulating cap layer **70** can be removed by the at least one anisotropic etch process. Further, the horizontal portions of the first semiconductor channel layer **601**L, the tunneling dielectric layer **505**L, the memory material layer **504**L, and the at least one blocking dielectric layer (**501**L, **503**L) at a bottom of

each cavity 49' can be removed to form openings in remaining portions thereof. Each of the first semiconductor channel layer 601L, the tunneling dielectric layer 505L, the memory material layer 504L, and the at least one blocking dielectric layer (501L, 503L) can be etched by anisotropic etch process.

Each remaining portion of the first semiconductor channel layer 601L constitutes a first semiconductor channel portion 601. Each remaining portion of the tunneling dielectric layer 505L constitutes a tunneling dielectric 505. Each remaining portion of the memory material layer 504L is herein referred to as a charge storage structure 504. In one embodiment, the charge storage structure 504 can be a contiguous layer, i.e., can be a charge storage layer. Each remaining portion of the second blocking dielectric layer 503L is herein referred to as a second blocking dielectric 503. Each remaining portion of the first blocking dielectric layer 501L is herein referred to as a first blocking dielectric 501. A surface of the semiconductor material layer 10 can be physically exposed underneath the opening through the first semiconductor channel portion 601, the tunneling dielectric 505, the charge storage structure 504, and the at least one blocking dielectric (501, 503). Optionally, the physically exposed semiconductor surface at the bottom of each cavity 49' can be vertically recessed so that the recessed semiconductor surface underneath the cavity 49' is vertically offset from the topmost surface of the semiconductor material layer 10 by a recess distance rd. A tunneling dielectric 505 is embedded within a charge storage structure 504. The charge storage structure 504 can comprise a charge trapping material or a floating gate material.

In one embodiment, the first semiconductor channel portion 601, the tunneling dielectric 505, the charge storage structure 504, the second blocking dielectric 503, and the first blocking dielectric 501 can have vertically coincident sidewalls. As used herein, a first surface is "vertically coincident" with a second surface if there exists a vertical plane including both the first surface and the second surface. Such a vertical plane may, or may not, have a horizontal curvature, but does not include any curvature along the vertical direction, i.e., extends straight up and down.

Referring to FIG. 2C, a second semiconductor channel layer 602L can be deposited directly on the semiconductor surface of the semiconductor material layer 10 in the substrate (9, 10), and directly on the first semiconductor channel portion 601. The second semiconductor channel layer 602L includes a semiconductor material such as at least one elemental semiconductor material, at least one III-V compound semiconductor material, at least one II-VI compound semiconductor material, at least one organic semiconductor material, or other semiconductor materials known in the art. In one embodiment, the second semiconductor channel layer 602L includes amorphous silicon or polysilicon. The second semiconductor channel layer 602L can be formed by a conformal deposition method such as low pressure chemical vapor deposition (LPCVD). The thickness of the second semiconductor channel layer 602L can be in a range from 2 nm to 10 nm, although lesser and greater thicknesses can also be employed. The second semiconductor channel layer 602L may partially fill the cavity 49' in each memory opening, or may fully fill the cavity in each memory opening.

The materials of the first semiconductor channel portion 601 and the second semiconductor channel layer 602L are collectively referred to as a semiconductor channel material. In other words, the semiconductor channel material is a set of all semiconductor material in the first semiconductor channel portion 601 and the second semiconductor channel layer 602L.

Referring to FIG. 2D, in case the cavity 49' in each memory opening is not completely filled by the second semiconductor channel layer 602L, a dielectric core layer 62L can be deposited in the cavity 49' to fill any remaining portion of the cavity 49' within each memory opening. The dielectric core layer 62L includes a dielectric material such as silicon oxide or organosilicate glass. The dielectric core layer 62L can be deposited by a conformal deposition method such as low pressure chemical vapor deposition (LPCVD), or by a self-planarizing deposition process such as spin coating.

Referring to FIG. 2E, the horizontal portion of the dielectric core layer 62L can be removed, for example, by a recess etch from above the top surface of the insulating cap layer 70. Further, the horizontal portion of the second semiconductor channel layer 602L located above the top surface of the insulating cap layer 70 can be removed by a planarization process, which can employ a recess etch or chemical mechanical planarization (CMP). Each remaining portion of the second semiconductor channel layer 602L within a memory opening constitutes a second semiconductor channel portion 602.

Each adjoining pair of a first semiconductor channel portion 601 and a second semiconductor channel portion 602 can collectively form a semiconductor channel 60 through which electrical current can flow when a vertical NAND device including the semiconductor channel 60 is turned on. A tunneling dielectric 505 is embedded within a charge storage structure 504, and laterally surrounds a portion of the semiconductor channel 60. Each adjoining set of a first blocking dielectric 501, a second blocking dielectric 503, a charge storage structure 504, and a tunneling dielectric 505 collectively constitute a memory film 50, which can store electrical charges with a macroscopic retention time. In some embodiments, a first blocking dielectric 501 and/or a second blocking dielectric 503 may not be present in the memory film 50 at this step, and a blocking dielectric may be subsequently formed after formation of backside recesses. As used herein, a macroscopic retention time refers to a retention time suitable for operation of a memory device as a permanent memory device such as a retention time in excess of 24 hours.

The top surface of the remaining portion of the dielectric core layer 62L can be further recessed within each memory opening, for example, by a recess etch to a depth that is located between the top surface of the insulating cap layer 70 and the bottom surface of the insulating cap layer 70. Each remaining portion of the dielectric core layer 62L constitutes a dielectric core 62.

Referring to FIG. 2F, drain regions 63 can be formed by depositing a doped semiconductor material within each recessed region above the dielectric cores 62. The doped semiconductor material can be, for example, doped polysilicon. Excess portions of the deposited semiconductor material can be removed from above the top surface of the insulating cap layer 70, for example, by chemical mechanical planarization (CMP) or a recess etch to form the drain regions 63.

The exemplary memory stack structure can be embedded into the exemplary structure illustrated in FIG. 1. FIG. 3 illustrates the exemplary structure that incorporates multiple instances of the exemplary memory stack structure of FIG. 2F. The exemplary structure includes a semiconductor device, which comprises a stack (32, 42) including an

alternating plurality of material layers (e.g., the sacrificial material layers **42**) and insulating layers **32** located over a semiconductor substrate (**9**, **10**), and a memory opening extending through the alternating stack (**32**, **42**). The semiconductor device further comprises a first blocking dielectric **501** vertically extending from a bottommost layer (e.g., the bottommost sacrificial material layer **42**) of the stack to a topmost layer (e.g., the topmost sacrificial material layer **42**) of the stack, and contacting a sidewall of the memory opening and a horizontal surface of the semiconductor substrate. While the present disclosure is described employing the illustrated configuration for the memory stack structure, the methods of the present disclosure can be applied to alternative memory stack structures including a polycrystalline semiconductor channel.

Referring to FIG. **4**, at least one dielectric cap layer **71** can be optionally formed over the planarization dielectric layer **70**. In one embodiment, the at least one dielectric cap layer **71** can include dielectric materials through which deuterium atoms can permeate. For example, the at least one dielectric cap layer can include silicon oxide and/or a dielectric metal oxide.

Optionally, a portion of the alternating stack (**32**, **42**) can be removed, for example, by applying and patterning a photoresist layer with an opening and by transferring the pattern of the opening through the alternating stack (**32**, **42**) employing an etch such as an anisotropic etch. An optional trench extending through the entire thickness of the alternating stack (**32**, **42**) can be formed within an area that includes a peripheral device region **200** and a portion of a contact region **300**, which is adjacent to a device region **100** that includes an array of memory stack structures **55**. Subsequently, the trench can be filled with an optional dielectric material such as silicon oxide. Excess portions of the dielectric material can be removed from above the top surface of the at least one dielectric cap layer **71** by a planarization process such as chemical mechanical planarization and/or a recess etch. The top surfaces of the at least one dielectric cap layer **71** can be employed as a stopping surface during the planarization. The remaining dielectric material in the trench constitutes a dielectric material portion **64**.

A stepped cavity can be formed within the contact region **300**, which can straddle the dielectric material portion **64** and a portion of the alternating stack (**32**, **42**). Alternatively, the dielectric material portion **64** may be omitted and the stepped cavity **69** may be formed directly in the stack (**32**, **42**). The stepped cavity can have various stepped surfaces such that the horizontal cross-sectional shape of the stepped cavity changes in steps as a function of the vertical distance from the top surface of the substrate (**9**, **10**). In one embodiment, the stepped cavity can be formed by repetitively performing a set of processing steps. The set of processing steps can include, for example, an etch process of a first type that vertically increases the depth of a cavity by one or more levels, and an etch process of a second type that laterally expands the area to be vertically etched in a subsequent etch process of the first type. As used herein, a "level" of a structure including alternating plurality is defined as the relative position of a pair of a first material layer and a second material layer within the structure.

The dielectric material portion **64** can have stepped surfaces after formation of the stepped cavity, and a peripheral portion of the alternating stack (**32**, **42**) can have stepped surfaces after formation of the stepped cavity. As used herein, "stepped surfaces" refer to a set of surfaces that include at least two horizontal surfaces and at least two vertical surfaces such that each horizontal surface is adjoined to a first vertical surface that extends upward from a first edge of the horizontal surface, and is adjoined to a second vertical surface that extends downward from a second edge of the horizontal surface. A "stepped cavity" refers to a cavity having stepped surfaces.

A retro-stepped dielectric material portion **65** (i.e., an insulating fill material portion) can be formed in the stepped cavity by deposition of a dielectric material therein. A dielectric material such as silicon oxide can be deposited in the stepped cavity. Excess portions of the deposited dielectric material can be removed from above the top surface of the at least one dielectric cap layer **71**, for example, by chemical mechanical planarization (CMP). The remaining portion of the deposited dielectric material filling the stepped cavity constitutes the retro-stepped dielectric material portion **65**. As used herein, a "retro-stepped" element refers to an element that has stepped surfaces and a horizontal cross-sectional area that increases monotonically as a function of a vertical distance from a top surface of a substrate on which the element is present. If silicon oxide is employed for the retro-stepped dielectric material portion **65**, the silicon oxide of the retro-stepped dielectric material portion **65** may, or may not, be doped with dopants such as B, P, and/or F.

Referring to FIGS. **5**A and **5**B, at least one dielectric support pillar **7**P may be optionally formed through the retro-stepped dielectric material portion **65** and/or through the alternating stack (**32**, **42**). The plane A-A' in FIG. **5**B corresponds to the plane of the vertical cross-sectional view of FIG. **5**A. In one embodiment, the at least one dielectric support pillar **7**P can be formed in the contact region **300**, which is located adjacent to the device region **100**. The at least one dielectric support pillar **7**P can be formed, for example, by forming an opening extending through the retro-stepped dielectric material portion **65** and/or through the alternating stack (**32**, **42**) and at least to the top surface of the substrate (**9**, **10**), and by filling the opening with a dielectric material that is resistant to the etch chemistry to be employed to remove the sacrificial material layers **42**. In one embodiment, the at least one dielectric support pillar can include silicon oxide and/or a dielectric metal oxide such as aluminum oxide. In one embodiment, the portion of the dielectric material that is deposited over the at least one dielectric cap layer **71** concurrently with deposition of the at least one dielectric support pillar **7**P can be present over the at least one dielectric cap layer **71** as a dielectric pillar material layer **73**. The dielectric pillar material layer **73** and the at least one dielectric support pillar **7**P can be formed as a single contiguous structure of integral construction, i.e., without any material interface therebetween. In another embodiment, the portion of the dielectric material that is deposited over the at least one dielectric cap layer **71** concurrently with deposition of the at least one dielectric support pillar **7**P can be removed, for example, by chemical mechanical planarization or a recess etch. In this case, the dielectric pillar material layer **73** is not present, and the top surface of the at least one dielectric cap layer **71** can be physically exposed.

A photoresist layer (not shown) can be applied over the alternating stack (**32**, **42**) and/or the retro-stepped dielectric material portion **65**, and optionally over the and lithographically patterned to form at least one backside trench **79** in an area in which formation of a backside contact via structure is desired. The pattern in the photoresist layer can be transferred through the alternating stack (**32**, **42**) and/or the retro-stepped dielectric material portion **65** employing an anisotropic etch to form the at least one backside trench **79**,

which extends at least to the top surface of the substrate (**9**, **10**). In one embodiment, the at least one backside trench **79** can include a source contact opening in which a source contact via structure can be subsequently formed. If desired, a source region (not shown) may be formed by implantation of dopant atoms into a portion of the semiconductor material layer **10** through the backside trench **79**.

An etchant that selectively etches the second material of the sacrificial material layers **42** with respect to the first material of the insulating layers **32** can be introduced into the at least one backside trench **79**, for example, employing an etch process. Backside recesses **43** are formed in volumes from which the sacrificial material layers **42** are removed. The removal of the second material of the sacrificial material layers **42** can be selective to the first material of the insulating layers **32**, the material of the at least one dielectric support pillar **7**P, the material of the retro-stepped dielectric material portion **65**, the semiconductor material of the semiconductor material layer **10**, and the material of the outermost layer of the memory films **50**. In one embodiment, the sacrificial material layers **42** can include silicon nitride, and the materials of the insulating layers **32**, the at least one dielectric support pillar **7**P, and the retro-stepped dielectric material portion **65** can be selected from silicon oxide and dielectric metal oxides. In another embodiment, the sacrificial material layers **42** can include a semiconductor material such as polysilicon, and the materials of the insulating layers **32**, the at least one dielectric support pillar **7**P, and the retro-stepped dielectric material portion **65** can be selected from silicon oxide, silicon nitride, and dielectric metal oxides. In this case, the depth of the at least one backside trench **79** can be modified so that the bottommost surface of the at least one backside trench **79** is located within the dielectric pad layer **12**, i.e., to avoid physical exposure of the top surface of the semiconductor substrate layer **10**.

The etch process that removes the second material selective to the first material and the outermost layer of the memory films **50** can be a wet etch process employing a wet etch solution, or can be a gas phase (dry) etch process in which the etchant is introduced in a vapor phase into the at least one backside trench **79**. For example, if the sacrificial material layers **42** include silicon nitride, the etch process can be a wet etch process in which the exemplary structure is immersed within a wet etch tank including phosphoric acid, which etches silicon nitride selective to silicon oxide, silicon, and various other materials employed in the art. The at least one dielectric support pillar **7**P, the retro-stepped dielectric material portion **65**, and the memory stack structures **55** provide structural support while the backside recesses **43** are present within volumes previously occupied by the sacrificial material layers **42**.

Each backside recess **43** can be a laterally extending cavity having a lateral dimension that is greater than the vertical extent of the cavity. In other words, the lateral dimension of each backside recess **43** can be greater than the height of the backside recess **43**. A plurality of backside recesses **43** can be formed in the volumes from which the second material of the sacrificial material layers **42** is removed. The memory openings in which the memory stack structures **55** are formed are herein referred to as front side recesses or front side cavities in contrast with the backside recesses **43**. In one embodiment, the device region **100** comprises an array of monolithic three-dimensional NAND strings having a plurality of device levels disposed above the substrate (**9**, **10**). In this case, each backside recess **43** can define a space for receiving a respective word line of the array of monolithic three-dimensional NAND strings.

Each of the plurality of backside recesses **43** can extend substantially parallel to the top surface of the substrate (**9**, **10**). A backside recess **43** can be vertically bounded by a top surface of an underlying insulating layer **32** and a bottom surface of an overlying insulating layer **32**. In one embodiment, each backside recess **43** can have a uniform height throughout. Optionally, a backside blocking dielectric layer can be formed in the backside recesses.

FIGS. **6**A-**6**D illustrate processing steps that can be employed to form first exemplary electrically conductive layers according to a first embodiment of the present disclosure. Referring to FIG. **6**A, a vertical cross-sectional magnified view of a magnified region M in FIGS. **5**A and **5**B is illustrated, which includes a portion of the backside trench **79** and a plurality of backside recesses **43**. In one embodiment, a sidewall surface of at least one blocking dielectric (**501**, **503**) can be physically exposed at end portions of backside recesses **43**. The sidewall surface of the at least one blocking dielectric (**501**, **503**) is an outer sidewall surface of a memory film **50** illustrated in FIG. **2**F. Optionally, a backside blocking dielectric layer (not shown) including a blocking dielectric material can be formed on the physically exposed surfaces of the insulating layers **32** and the physically exposed sidewalls of the memory film **50** (See FIG. **2**F).

An optional metallic barrier material layer **148**L can be deposited in the backside recesses **43** and over the sidewall of the backside trench **79**. The metallic barrier material layer **148**L includes a metallic barrier material, which is a metallic material that blocks diffusion of metal elements therethrough. The metallic barrier material layer **148**L can be a conductive metallic nitride layer such as TiN, TaN, WN, or a combination or an alloy thereof. The thickness of the metallic barrier material layer **148**L can be in a range from 0.5 nm to 1.5 nm, although lesser and greater thicknesses can also be employed. The metallic barrier material layer **148**L can be deposited, for example, by chemical vapor deposition (CVD) or atomic layer deposition (ALD). In general, the thickness of the metallic barrier material layer **148**L can be thinner if cobalt is to be subsequently deposited on the sidewalls of the metallic barrier material layer **148**L than if tungsten is to be subsequently deposited on the sidewalls of the metallic barrier material layer **148**L. A backside cavity **43'** is present in each unfilled volume of the backside recess **43**, i.e., in each volume of the backside recess **43** that is not filled with the metallic barrier material layer **148**L.

Referring to FIG. **6**B, an anisotropic etch is performed to remove vertical portions of the metallic barrier material layer **148**L from the sidewalls of each backside trench **79**. The anisotropic etch can be a reactive ion etch that removes the material of the metallic barrier material layer **148**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Vertical portions of the metallic barrier material layer **148**L are removed from the sidewall of the backside trench **79**. Portions of the metallic barrier material layer **148**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**. Each metallic barrier material portion **148** can be a conformal material portion having a uniform thickness throughout. Sidewalls of the insulating layers **32** are physically exposed within each backside trench **79**. The metallic barrier material portions **148** are formed as a plurality structures that are vertically disjoined from one another.

Referring to FIG. **6**C, cobalt can be selectively deposited inside the backside cavities to form cobalt portions **48**. Deposition of cobalt can be performed by chemical vapor deposition (CVD) or atomic layer deposition (ALD). Chemical vapor deposition or atomic layer deposition of cobalt employs a cobalt precursor that can be easily vaporized to leave high-purity cobalt on a surface without causing surface damage. In one embodiment, an organometallic compound with relatively high vapor pressures and good thermal stability can be employed as the cobalt precursor gas to deposit cobalt without requiring hydrogen. In a non-limiting example, bis(cyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, or bis(pentamethylcyclopentadienyl)cobalt can be employed as a cobalt precursor gas in a CVD or ALD process. Alternatively, different precursor gases (such as $Co_2(CO)_8$) can also be employed for cobalt deposition.

Cobalt may be selectively nucleated on a metallic surface such as the surfaces of the metallic barrier material portions **148**. Thus, cobalt portions **48** can grow selectively only from the surfaces of the metallic barrier material portions **148**, and do not grow from the sidewalls of the insulating layers **32**. As such, the cobalt deposition process is a selective deposition process that proceeds from the surfaces of the metallic barrier material portions **148**, while cobalt is not deposited on the surfaces of the insulating layers **32**. Each cobalt portion **48** can be formed on surfaces of a respective metallic barrier material portion **148**, and specifically, on a pair of horizontal surfaces of the respective metallic barrier material portion **148** and an outer sidewall of the respective metallic barrier material portion **148**. Each deposited portion of cobalt constitutes one of the cobalt portions **48**.

The duration of the cobalt deposition process can be selected such that the cobalt portions **48** completely fill the backside cavities **43'**. In one embodiment, a convex sidewall of each cobalt portion **48** can protrude into the backside trench **79** due to the selective nature of the cobalt deposition process. A combination of a metallic barrier material portion **148** and a cobalt portion **48** embedded within the metallic barrier material portion **148** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can consist of a cobalt portion **48** and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. In one embodiment, the electrically conductive layers **46** can be employed as is, and subsequent processing steps of FIG. **16** can be performed.

Alternatively, the cobalt portions **48** can be laterally recessed. FIG. **6**D illustrates the optional step of laterally recessing the cobalt portions **48**, in which cobalt can be isotropically etched employing an isotropic etch chemistry. The lateral recessing of the cobalt portions **48** can be performed by an isotropic dry etch or a wet etch. The lateral recess distance lrd, as measured between a vertical plane including a sidewall of the backside trench **79** and a sidewall of a cobalt portion **48** after the lateral recess, can be in a range from 3 nm to 5 nm, although lesser and greater thickness can be employed. A proximal sidewall of each cobalt portion **48** is laterally spaced from the memory film **50** (See FIG. **2**F) by a vertical portion of a respective metallic barrier material portion **148**. Each cobalt portion **48** can be laterally recessed from the backside trench **79**. Specifically, a distal sidewall of each cobalt portion **48** (e.g., a left side sidewall in FIG. **6**D) is more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. The lateral recessing of the sidewalls of the cobalt portions **48** is an optional process.

FIGS. **7**A and **7**B illustrate processing steps for forming second exemplary electrically conductive layers according to a second embodiment of the present disclosure. The structure of FIG. **7**A can be derived from the structure of FIG. **6**A by depositing a cobalt layer **48**L on the metallic barrier material layer **148**L. The cobalt layer **48**L can be deposited employing the same deposition methods as the deposition methods employed to deposit the cobalt portions **48**. Because the surfaces of the metallic barrier material layer **148**L are present within the backside recesses **43** and in the backside trench **79**, the cobalt layer **48**L can be deposited as a contiguous layer filling the backside cavities **43'** and extending through the entire height of the backside trench **79**.

Referring to FIG. **7**B, the cobalt layer **48**L can be etched to physically expose sidewalls of the insulating layers **32**. The etch of cobalt can be performed by an isotropic dry etch process or a wet etch process. The isotropic etch of cobalt may, or may not, be selective to the material of the metallic barrier material layer **148**L. The cobalt layer **48**L can be divided into disjoined discrete material portions located within each respective level. Each disjoined discrete material portion of the cobalt layer **48**L is herein referred to as a cobalt portion **48**. In one embodiment, an outer sidewall of each cobalt portion **48** can be laterally recessed from the sidewall of the backside trench **79** by a lateral recess distance lrd. A proximal sidewall of each cobalt portion **48** is laterally spaced from the memory film **50** (See FIG. **2**F) by a vertical portion of a respective metallic barrier material portion **148**. Each cobalt portion **48** can be laterally recessed from the backside trench **79**. Specifically, a distal sidewall of each cobalt portion **48** is more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd.

Subsequent to the etching of the cobalt layer **48**L or concurrently with etching of the cobalt layer **48**L, an anisotropic etch can be performed to remove vertical portions of the metallic barrier material layer **148**L from the sidewalls of each backside trench **79**. The anisotropic etch can be a reactive ion etch that removes the material of the metallic barrier material layer **148**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Portions of the metallic barrier material layer **148**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**.

Thus, portions of the contiguous cobalt layer **48**L are etched back prior to removing the vertical portions of the metallic barrier material layer **148**L. Each remaining portion of the contiguous cobalt layer **48**L constitutes a cobalt portion **48** of the electrically conductive layers **46**. The cobalt portions **48** may have distal sidewalls that are laterally recessed from the sidewalls of the backside trench **79**, or may have distal sidewalls that are vertically coincident with the sidewalls of the backside trench **79**. Each metallic barrier material portion **148** can be a conformal material portion having a uniform thickness throughout. Sidewalls of the insulating layers **32** are physically exposed within each backside trench **79**. Each cobalt portion **48** can be formed on surfaces of a respective metallic barrier material portion **148**, and specifically, on a pair of horizontal surfaces of the respective metallic barrier material portion **148** and an outer

sidewall of the respective metallic barrier material portion **148**. A combination of a metallic barrier material portion **148** and a cobalt portion **48** embedded within the metallic barrier material portion **148** constitutes an electrically conductive layer **46** at each level. Each electrically conductive layer **46** can consist of a cobalt portion **48** and a metallic barrier material portion **148**.

FIGS. **8**A-**8**C illustrate processing steps for forming third exemplary electrically conductive layers according to a third embodiment of the present disclosure. The structure of FIG. **8**A can be derived from the structure of FIG. **6**A by depositing a metallic material layer **47**L on the metallic barrier material layer **148**L. The metallic material layer **47**L can be a contiguous layer extending through the entire vertical height of the backside trench **79**. The metallic material layer **47**L can include any metallic material other than cobalt. In one embodiment, the metallic material layer **47**L can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material layer **47**L can comprise molybdenum, tungsten, copper, ruthenium, or titanium, or a combination thereof. In one embodiment, the metallic material layer **47**L can comprise tungsten or a tungsten-containing intermetallic alloy. The thickness of the metallic material layer **47**L can be selected such that the backside cavities **43'** are not completely filled with the metallic material layer **47**L.

Referring to FIG. **8**B, an anisotropic etch is performed to remove vertical portions of the metallic barrier material layer **148**L and the metallic material layer **47**L from the sidewalls of each backside trench **79**. The anisotropic etch can be a reactive ion etch that removes the materials of the metallic barrier material layer **148**L and the metallic material layer **47**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Portions of the metallic barrier material layer **148**L and the metallic material layer **47**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**. Each remaining portion of the metallic material layer **47**L inside the backside recesses **43** constitutes a metallic material portion **47**. Each metallic barrier material portion **148** can be a conformal material portion having a uniform thickness throughout. Likewise, each metallic material portion **47** can be a conformal material portion having another uniform thickness throughout. Sidewalls of the insulating layers **32** are physically exposed within each backside trench **79**. The metallic barrier material portions **148** are formed as a plurality structures that are vertically disjoined from one another. Further, the metallic material portions **47** are formed as a plurality structures that are vertically disjoined from one another. Alternately, the processing steps of FIGS. **6**A and **6**B can be performed, and the metallic material portions **47** can be deposited by a selective deposition process.

Referring to FIG. **8**C, cobalt can be deposited inside the backside cavities **43'** to form cobalt portions **48**. Deposition of cobalt can be performed employing the same methods as in the first embodiment. Cobalt portions **48** grow only from the surfaces of the metallic material portions **47** and the metallic barrier material portions **148**, and do not grow from the sidewalls of the insulating layers **32**. As such, the cobalt deposition process is a selective deposition process that proceeds from the surfaces of the metallic material portions **47**, while cobalt is not deposited on the surfaces of the insulating layers **32**. Each cobalt portion **48** can be formed on surfaces of a respective metallic material portion **47**, and specifically, on a pair of horizontal surfaces of the respective metallic material portion **47** and an outer sidewall of the respective metallic material portion **47**. Each deposited portion of cobalt constitutes one of the cobalt portions **48**.

The duration of the cobalt deposition process can be selected such that the cobalt portions **48** completely fill the backside cavities **43'**. A combination of a metallic barrier material portion **148**, a metallic material portion **47** embedded within the metallic barrier material portion **148**, and a cobalt portion **48** embedded within the metallic material portion **47** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a cobalt portion **48**, a metallic material portion **47** including a metallic material other than cobalt, and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Optionally, the cobalt portions **48** and/or the metallic material portions **47** can be laterally recessed from the sidewall of the backside trench **79**. In this case, each of the electrically conductive layers **46** comprises a metallic barrier material portion **148** contacting an outer sidewall of the memory film **50**, a metallic material portion **47** containing a material other than cobalt and contacting the metallic barrier material portion **148**, and a respective cobalt portion **48** contacting horizontal surfaces of the metallic material portion **47** and not contacting the metallic barrier material portion **148**.

FIGS. **9**A-**9**C illustrate processing steps for forming fourth exemplary electrically conductive layers according to a fourth embodiment of the present disclosure. The structure of FIG. **9**A can be derived from the structure of FIG. **6**A by depositing a metallic material layer **47**L on the metallic barrier material layer **148**L. The metallic material layer **47**L can include any metallic material other than cobalt. In one embodiment, the metallic material layer **47**L can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material layer **47**L can comprise molybdenum, tungsten, copper, titanium, ruthenium, or a combination thereof. In one embodiment, the metallic material layer **47**L can comprise tungsten or a tungsten-containing intermetallic alloy. The thickness of the metallic material layer **47**L can be selected such that the backside cavities **43'** are completely filled with the metallic material layer **47**L.

Referring to FIG. **9**B, vertical portions of the metallic material layer **47**L and the metallic barrier material layer **148**L are removed from the sidewall of the backside trench **79**. The metallic material layer **47**L can be isotropically etched to physically expose the sidewall of the metallic barrier material layer **148**L located adjacent to the sidewall of each backside trench **79**. The isotropic etch of tungsten can be performed by an isotropic dry etch process or a wet etch process. The isotropic etch of the metallic material layer **47**L can be selective to the material of the metallic barrier material layer **148**L. The duration of the isotropic etch can be selected such that remaining portions of the metallic material layer **47**L are laterally recessed from the sidewall of the backside trench **79** by a lateral recess distance lrd. The metallic material layer **47**L is divided into disjoined discrete material portions located within each respective level. Each disjoined discrete material portion of the metallic material layer **47**L constitutes a metallic material portion **47**.

Subsequently, an anisotropic etch is performed to remove vertical portions of the metallic barrier material layer **148**L from the sidewalls of each backside trench **79**. The aniso-

tropic etch can be a reactive ion etch that removes the material of the metallic barrier material layer **148**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Portions of the metallic barrier material layer **148**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**. Thus, portions of the metallic material layer **47**L are etched back prior to removing the vertical portions of the metallic barrier material layer **148**L. Each remaining portion of the metallic material layer **47**L constitutes a metallic material portion **47** of electrically conductive layers to be formed. Alternately, an anisotropic etch may be employed to remove the vertical portions of the metallic material layer **47**L and the metallic barrier material layer **148**L, and an isotropic etch may be employed to laterally recess the metallic material portions **47**.

In one embodiment, the lateral recess distance lrd can be greater than the height of a backside recess **43**, which is the same as the height of a metallic barrier material portion **148** within the backside recess **43**. In one embodiment, the lateral recess distance lrd can be in a range from 15% to 85% of the lateral distance between the sidewall of the backside trench **79** and the outer sidewall of the memory film **50**, e.g., the outer sidewall of the at least one blocking dielectric layer (**501**L, **503**L). In one embodiment, the lateral recess distance lrd can be determined to optimize the resistance of the electrically conductive layers to be formed in the backside recesses and the overall stress that the electrically conductive layers will generate. A distal sidewall of each metallic material portion **47** is more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. A proximal sidewall of each metallic material portion **47** can contact an outer sidewall of a metallic barrier material portion **148**.

Referring to FIG. **9**C, cobalt can be deposited inside the backside cavities **43'** to form cobalt portions **48**. Deposition of cobalt can be performed employing the same methods as in the first embodiment. Cobalt portions **48** grow only from the surfaces of the metallic material portions **47** and the metallic barrier material portions **148**, and do not grow from the sidewalls of the insulating layers **32**. As such, the cobalt deposition process is a selective deposition process that proceeds from the surfaces of the metallic barrier material portions **148** and the surfaces of the metallic material portions **47**, while cobalt is not deposited on the surfaces of the insulating layers **32**. Thus, each cobalt portion **48** can be formed on a respective metallic material portion **47** and a respective metallic barrier material portion **148**, and specifically, on a pair of horizontal surfaces of the respective metallic barrier material portion **148** and an outer sidewall of the respective metallic material portion **47**. Each deposited portion of cobalt constitutes one of the cobalt portions **48**.

In one embodiment, the duration of the cobalt deposition process can be selected such that the cobalt portions **48** completely fill the backside cavities **43'**. A combination of a metallic barrier material portion **148**, a cobalt portion **48** contacting horizontal surfaces of the metallic barrier material portion **148**, and a metallic material portion **47** encapsulated by the metallic barrier material portion **148** and the cobalt portion **48** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a cobalt portion **48**, a metallic material portion **47** including a metallic material other than cobalt, and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Optionally, an anisotropic etch or an isotropic etch can be performed to remove regions of the cobalt portions **48** inside backside trench **79**. In this case, the cobalt portions **48** can have sidewalls that are vertically coincident with sidewalls of the insulating layers **32** around the backside trench **79**. Optionally, the cobalt portions **48** may be laterally recessed from the sidewall of the backside trench **79**, for example, by a recess etch. In one embodiment, each cobalt portion **48** is laterally spaced from a vertical portion of a metallic barrier material portion **148** located at a same level by a respective metallic material portion **47** that comprises tungsten or a tungsten alloy.

FIGS. **10**A and **10**B illustrate processing steps for forming fifth exemplary electrically conductive layers according to a fifth embodiment of the present disclosure. The structure of FIG. **10**A can be derived from the structure of FIG. **9**B by etching physically exposed portions of the metallic barrier material portions **148**.

Alternatively, the structure of FIG. **10**A can be derived from the structure of FIG. **9**A by simultaneously etching, or by sequentially etching, the metallic material layer **47**L and the metallic barrier material layer **148**L. At least one isotropic etch process can be employed to laterally recess the metallic material layer **47**L and the metallic barrier material layer **148**L, and to form backside recesses **43'**. After the isotropic etching of the metallic material layer **47**L, the metallic material layer **47**L can be divided into disjoined discrete material portions located within each respective level. Each disjoined discrete material portion of the metallic material layer **47**L is herein referred to as a metallic material portion **47**.

Subsequently, an isotropic etch process is employed to etch the physically exposed portions of the metallic barrier material layer **148**L. In other words, an isotropic etch is employed to remove physically exposed portions of the metallic barrier material layer **148**L at the processing step of FIG. **10**A in lieu of an anisotropic etch that is employed to remove the portions of the metallic barrier material layer **148**L within the backside trench **79** at the processing steps of FIG. **9**B. The isotropic etch process that etches the physically exposed portions of the metallic barrier material layer **148**L can be an isotropic dry etch or a wet etch.

The isotropic etch divides the metallic barrier material layer **148**L into disjoined discrete material portions located within each respective level. Each disjoined discrete material portion of the metallic barrier material layer **148**L is herein referred to as a metallic barrier material portion **148**. Thus, portions of the metallic material layer **47**L are etched back prior to removing the physically exposed portions of the metallic barrier material layer **148**L. A distal sidewall of each metallic material portion **47** and a distal sidewall of each metallic barrier material portion **148** can be more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. A proximal sidewall of each metallic material portion **47** can contact an outer sidewall of a metallic barrier material portion **148**.

Referring to FIG. **10**B, cobalt can be deposited inside the backside cavities **43'** to form cobalt portions **48**. Deposition of cobalt can be performed employing the same methods as in the first embodiment. Cobalt portions **48** grow only from the surfaces of the metallic material portions **47** and the metallic barrier material portions **148**, and do not grow from the sidewalls of the insulating layers **32**. As such, the cobalt deposition process is a selective deposition process that proceeds from the surfaces of the metallic barrier material

portions **148** and the surfaces of the metallic material portions **47**, while cobalt is not deposited on the surfaces of the insulating layers **32**. Thus, each cobalt portion **48** can be formed on a respective metallic material portion **47** and a respective metallic barrier material portion **148**, and specifically, on vertical sidewalls of the respective metallic material portion **47** and the respective metallic barrier material portion **148**. Each deposited portion of cobalt constitutes one of the cobalt portions **48**.

In one embodiment, the duration of the cobalt deposition process can be selected such that the cobalt portions **48** completely fill the backside cavities **43'**. A combination of a metallic barrier material portion **148**, a cobalt portion **48** contacting horizontal surfaces of a pair of insulating layers **32**, and a metallic material portion **47** encapsulated by the metallic barrier material portion **148** and the cobalt portion **48** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a cobalt portion **48**, a metallic material portion **47** including a metallic material other than cobalt, and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Optionally, an anisotropic etch or an isotropic etch can be performed to remove regions of the cobalt portions **48** inside backside trench **79**. In this case, the cobalt portions **48** can have sidewalls that are vertically coincident with sidewalls of the insulating layers **32** around the backside trench **79**. Optionally, the cobalt portions **48** may be laterally recessed from the sidewall of the backside trench **79**, for example, by a recess etch. Each cobalt portion **48** contacts a horizontal surface of an overlying dielectric layer (e.g., an overlying insulating layer **32**) and a horizontal surface of an underlying dielectric layer (e.g., an underlying insulating layer **32**).

FIGS. **11**A and **11**B illustrate processing steps for forming sixth exemplary electrically conductive layers according to a sixth embodiment of the present disclosure. The structure of FIG. **11**A can be derived from the structure of FIG. **6**A by depositing a cobalt layer **48**L on the metallic barrier material layer **148**L. The cobalt layer **48**L can be deposited employing the same deposition methods as the deposition methods employed to deposit the cobalt portions **48** of FIG. **6**C or the cobalt layer **48**L of FIG. **7**A. The thickness of the cobalt layer **48**L can be selected such that the backside cavities **43'** are not completely filled with the cobalt layer **48**L. For example, the duration of the cobalt deposition process in a chemical vapor deposition process or the number of cycles in an atomic layer deposition process can be selected such that the backside recesses **43** are not completely filled at the end of the deposition process. Thus, a backside cavity **43'** is present within each backside recess **43** after formation of the cobalt layer **48**L.

Referring to FIG. **11**B, an anisotropic etch is performed to remove vertical portions of the metallic barrier material layer **148**L and the cobalt layer **48**L from the sidewalls of each backside trench **79**. The anisotropic etch can be a reactive ion etch that removes the materials of the metallic barrier material layer **148**L and the cobalt layer **48**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Portions of the metallic barrier material layer **148**L and the cobalt layer **48**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**. Each remaining portion of the cobalt layer **48**L inside the backside recesses **43** constitutes a cobalt portion **48**. Each metallic barrier material portion **148** can be a conformal material portion having a uniform thickness throughout. Likewise, each cobalt portion **48** can be a conformal material portion having another uniform thickness throughout. Sidewalls of the insulating layers **32** are physically exposed within each backside trench **79**. The metallic barrier material portions **148** are formed as a plurality structures that are vertically disjoined from one another. Further, the cobalt portions **48** are formed as a plurality structures that are vertically disjoined from one another. Each cobalt portion **48** of the electrically conductive layers **46** is formed on surfaces of a respective metallic barrier material portion **148**.

Referring to FIG. **11**C, a metallic material can be deposited inside the backside cavities **43'** to form metallic material portions **47**. The metallic material portions **47** can include any metallic material other than cobalt. In one embodiment, the metallic material portions **47** can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material portions **47** can comprise molybdenum, tungsten, copper, titanium, ruthenium, or a combination thereof. In one embodiment, the metallic material portions **47** can comprise tungsten or a tungsten-containing intermetallic alloy.

Deposition of the metallic material can be performed employing the same methods as in the third embodiment. In one embodiment, the metallic material portions **47** grow from the surfaces of the cobalt portions **48**, and do not grow from the sidewalls of the insulating layers **32**. As such, the metallic material deposition process is a selective deposition process that proceeds from the surfaces of the cobalt portions **48**, while the metallic material is not deposited on the surfaces of the insulating layers **32**. Thus, each metallic material portion **47** can be formed on surfaces of a respective cobalt portion **48**, and specifically, on a pair of horizontal surfaces of the respective cobalt portion **48** and an outer sidewall of the respective cobalt portion **48**. Each deposited portion of metallic material constitutes one of the metallic material portions **47**.

The duration of the metallic material deposition process can be selected such that the metallic material portions **47** completely fill the backside cavities **43'**. A metallic material portion **47** is formed on a respective cobalt portion **48** in each backside cavity **43'**, i.e., in the vacant portion of each backside recess. A combination of a metallic barrier material portion **148**, a cobalt portion **48** embedded within the metallic barrier material portion **148**, and a metallic material portion **47** embedded within the cobalt portion **48** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a cobalt portion **48**, a metallic material portion **47** including a metallic material other than cobalt, and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Each metallic material portion **47** is vertically and laterally spaced from a metallic barrier material portion **148** located at a same level by a respective cobalt portion **48**. Optionally, the cobalt portions **48** and/or the metallic material portions **47** can be laterally recessed from the sidewall of the backside trench **79**.

FIGS. **12A-12**C illustrate processing steps for forming seventh exemplary electrically conductive layers according to a seventh embodiment of the present disclosure. The structure of FIG. **12**A can be the same as the structure of FIG. **7**A according to the second embodiment, and can be

formed employing the same method as the second embodiment. In one embodiment, the cobalt layer **48**L can consist essentially of cobalt.

Referring to FIG. **12**B, the cobalt layer **48**L can be isotropically etched to physically expose the sidewall of the metallic barrier material layer **148**L located adjacent to the sidewall of each backside trench **79**. The isotropic etch of cobalt can be performed by an isotropic dry etch process or a wet etch process. The isotropic etch of the cobalt layer **48**L can be selective to the material of the metallic barrier material layer **148**L. The duration of the isotropic etch can be selected such that remaining portions of the cobalt layer **48**L are laterally recessed from the sidewall of the backside trench **79** by a lateral recess distance lrd. The cobalt layer **48**L is divided into disjoined discrete material portions located within each respective level. Each disjoined discrete material portion of the cobalt layer **48**L is herein referred to as a cobalt portion **48**. Each cobalt portion **48** of the electrically conductive layers **46** is formed on surfaces of a respective metallic barrier material portion **148**. Alternatively, a combination of an anisotropic etch and an isotropic etch can be employed to form the structure of FIG. **12**B.

In one embodiment, the lateral recess distance lrd can be greater than the height of a backside recess **43**, which is the same as the height of a metallic barrier material portion **148** within the backside recess **43**. In one embodiment, the lateral recess distance lrd can be in a range from 15% to 85% of the lateral distance between the sidewall of the backside trench **79** and the outer sidewall of the memory film **50**, e.g., the outer sidewall of the at least one blocking dielectric layer (**501**L, **503**L). In one embodiment, the lateral recess distance lrd can be determined to optimize the resistance of the electrically conductive layers to be formed in the backside recesses and the overall stress that the electrically conductive layers will generate. A distal sidewall of each cobalt portion **48** is more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. A proximal sidewall of each cobalt portion **48** can contact an outer sidewall of a metallic barrier material portion **148**. A proximal sidewall of each cobalt portion **48** is laterally spaced from the memory film **50** by a vertical portion of a respective metallic barrier material portion **148**, and each cobalt portion **48** is laterally recessed from the backside trench **79**.

Subsequently, an anisotropic etch is performed to remove vertical portions of the metallic barrier material layer **148**L from the sidewalls of each backside trench **79**. The anisotropic etch can be a reactive ion etch that removes the material of the metallic barrier material layer **148**L selective to the material of the insulating layers **32** and the material of the semiconductor material layer **10**. Portions of the metallic barrier material layer **148**L inside the backside recesses **43** are not removed by the anisotropic etch. Each remaining portion of the metallic barrier material layer **148**L inside the backside recesses **43** constitutes a metallic barrier material portion **148**. Thus, portions of the cobalt layer **48**L are etched back prior to removing the vertical portions of the metallic barrier material layer **148**L. Each remaining portion of the cobalt layer **48**L constitutes a cobalt portion **48** of electrically conductive layers to be formed.

Referring to FIG. **12**C, a metallic material can be deposited inside the backside cavities **43'** to form metallic material portions **47**. The metallic material portions **47** can include any metallic material other than cobalt. In one embodiment, the metallic material portions **47** can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material portions **47** can comprise molybdenum, tungsten, copper, titanium, ruthenium, or a combination thereof. In one embodiment, the metallic material portions **47** can comprise tungsten or a tungsten-containing intermetallic alloy. Deposition of metallic material can be performed employing the same methods as in the third embodiment. The metallic material portions **47** grow only from the surfaces of the cobalt portions **48** and the metallic barrier material portions **148**, and do not grow from the sidewalls of the insulating layers **32**. As such, the metallic material deposition process is a selective deposition process that proceeds from the surfaces of the metallic barrier material portions **148** and the surfaces of the cobalt portions **48**, while the metallic material is not deposited on the surfaces of the insulating layers **32**. Thus, each metallic material portion **47** can be formed on a respective cobalt portion **48** and a respective metallic barrier material portion **148**, and specifically, on a pair of horizontal surfaces of the respective metallic barrier material portion **148** and an outer sidewall of the respective cobalt portion **48**. Each deposited portion of metallic material constitutes one of the metallic material portions **47**.

In one embodiment, the duration of the metallic material deposition process can be selected such that the metallic material portions **47** completely fill the backside cavities **43'**. A metallic material portion **47** is formed on a respective cobalt portion **48** in each backside cavity **43'**, i.e., in the vacant portion of each backside recess. A combination of a metallic barrier material portion **148**, a metallic material portion **47** contacting horizontal surfaces of the metallic barrier material portion **148**, and a cobalt portion **48** encapsulated by the metallic barrier material portion **148** and the metallic material portion **47** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a metallic material portion **47**, a cobalt portion **48** including cobalt, and a metallic barrier material portion **148** including a metallic material other than cobalt. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Each metallic material portion **47** contacts a pair of horizontal surfaces of a metallic barrier material portion **148** located at the same level and a distal sidewall of the cobalt portion **48** located at the same level. Optionally, an anisotropic etch can be performed to remove regions of the metallic material portions **47** inside backside trench **79**. In this case, the metallic material portions **47** can have sidewalls that are vertically coincident with sidewalls of the insulating layers **32** around the backside trench **79**. Optionally, the metallic material portions **47** may be laterally recessed from the sidewall of the backside trench **79**, for example, by a recess etch.

FIGS. **13**A-**13**B illustrate processing steps for forming eighth exemplary electrically conductive layers according to an eighth embodiment of the present disclosure. The structure of FIG. **13**A can be derived from the exemplary structure of FIG. **12**B by isotropically etching physically exposed portions of each metallic barrier material portion **148**. Alternately, the metallic barrier material portions **148** can be laterally recessed at about the same etch rate as the cobalt portion **48** from the exemplary structure of FIG. **12**A.

Referring to FIG. **13**B, the processing steps of FIG. **12**C can be performed to form the metallic material portions **47**, which can be, for example, tungsten portions. The metallic material portions **47** grow from the respective vertical metallic surfaces of the metallic barrier material portion **148** and the cobalt portion **48** at each level. Each metallic material portion **47** can contact a horizontal surface of an

underlying dielectric layer (which can be, for example, an underlying insulating layer **32**) and a horizontal surface of an overlying dielectric layer (which can be, for example, an overlying insulating layer **32**).

FIGS. **14**A-**14**E illustrate processing steps for forming ninth exemplary electrically conductive layers according to a ninth embodiment of the present disclosure. The structure of FIG. **14**A can be derived from the structure of FIGS. **5**A and **5**B by forming a backside blocking dielectric layer **51** prior to formation of a metallic barrier material layer **148**L. The backside blocking dielectric layer **51** includes a dielectric material, which can comprise a high dielectric constant (high-k) dielectric material having a dielectric constant greater than 7.9 (such as aluminum oxide), and/or silicon oxide and/or silicon nitride. The backside blocking dielectric layer **51** can be formed, for example, by chemical vapor deposition (CVD) or atomic layer deposition (ALD). The thickness of the backside blocking dielectric layer **51** can be in a range from 0.5 nm to 1.5 nm, although lesser and greater thicknesses can also be employed. The metallic barrier material layer **148**L can be formed in the same manner as in the first embodiment.

Referring to FIG. **14**B, a disposable material layer **143**L is formed in the backside cavities **43'**. The disposable material layer **143**L can fill the entirety of the backside cavities **43'**. As used herein, a "disposable" material refers to a temporary material that is subsequently removed. The disposable material layer **143**L includes a material that can be removed selective to the material of the metallic barrier material layer **148**L. In one embodiment, the disposable material layer **143**L can comprise a semiconductor material such as polysilicon, amorphous silicon, a silicon-germanium alloy, or a combination thereof. The disposable material layer **143**L can be deposited, for example, by chemical vapor deposition.

Referring to FIG. **14**C, the material of the disposable material layer **143**L and the metallic barrier material layer **148**L are isotropically or anisotropically etched to physically expose sidewalls of the backside blocking dielectric layer **51**. The etch of the disposable material layer **143**L can be performed by a dry etch or a wet etch. For example, if the disposable material layer **143**L comprises silicon, the disposable material layer **143**L can be etched by an etch process employing one or more of BCl_3; a combination of $SiCl_4$, Cl_2, and HCl; a combination of O_2, $SiCl_4$, and HCl; SF_6; and NF_3. Each remaining portion of the disposable material layer **143**L within a backside recess is herein referred to as a disposable material portion **143**.

Subsequent to, or concurrently with, the etch of the vertical portion of the disposable material layer **143**L, physically exposed portions of the metallic barrier material layer **148**L is removed by an etch selective to the backside blocking dielectric layer **51**. Each remaining portion of the metallic barrier material layer **148**L constitutes a metallic barrier material portion **148**. In other words, a metallic barrier material portion **148** and a disposable material portion **143** can be formed at each level of the of backside recesses by removing vertical portions of the disposable material layer **143**L and the metallic barrier material layer **148**L, respectively.

Referring to FIG. **14**D, the disposable material portions **143** can be removed by an isotropic etch that etches the material of the disposable material portions **143**. A backside cavity **43'** can be formed within the volume of each backside recess.

Referring to FIG. **14**E, the processing step of FIG. **6**C can be performed to form cobalt portions **48**. Each cobalt portion **48** is embedded within a metallic barrier material portion **148**. Optionally, the processing steps of FIG. **6**D may be performed.

A combination of a metallic barrier material portion **148** and a cobalt portion **48** embedded within the metallic barrier material portion **148** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can consist of a cobalt portion **48** and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be vertically spaced from an overlying insulating layer **32**, an underlying insulating layer **32**, and the memory film **50** by the backside blocking dielectric layer **51**. Each cobalt portion **48** of the electrically conductive layers **46** is formed on surfaces of a respective metallic barrier material portion **148**. Specifically, each cobalt portion **48** of the electrically conductive layers **46** is formed on a pair of horizontal surfaces of the respective metallic barrier material portion and an outer sidewall of the respective metallic barrier material portions. The disposable material layer **143**L may be used in conjunction with other embodiments.

Referring to FIG. **15**, the exemplary structure is shown after formation of a plurality of electrically conductive layers **46**, which can be any of the electrically conductive layers **46** according to the first through ninth embodiments as described above.

Each electrically conductive layer **46** can function as a combination of a plurality of control gate electrodes and a word line electrically connecting, i.e., electrically shorting, the plurality of control gate electrodes. The plurality of control gate electrodes within each electrically conductive layer **46** can include control gate electrodes located at the same level for the vertical memory devices including the memory stack structures **55**. In other words, each electrically conductive layer **46** can be a word line that functions as a common control gate electrode for the plurality of vertical memory devices.

Referring to FIG. **16**, an insulating spacer **74** can be formed on the sidewalls of the backside trench **79** by deposition of a contiguous dielectric material layer and an anisotropic etch of its horizontal portions. The insulating spacer **74** includes a dielectric material, which can comprise, for example, silicon oxide, silicon nitride, a dielectric metal oxide, a dielectric metal oxynitride, or a combination thereof. The thickness of the insulating spacer **74**, as measured at a bottom portion thereof, can be in a range from 1 nm to 50 nm, although lesser and greater thicknesses can also be employed. In one embodiment, the thickness of the insulating spacer **74** can be in a range from 3 nm to 10 nm.

A photoresist layer (not shown) can be applied over the topmost layer of the exemplary structure (which can be, for example, the dielectric pillar material layer **73**) and in the cavity laterally surrounded by the insulating spacer **74**, and is lithographically patterned to form various openings in a peripheral device region. The locations and the shapes of the various openings are selected to correspond to electrical nodes of the semiconductor devices in the peripheral device region **200** to be electrically contacted by contact via structures. An anisotropic etch is performed to etch through the various layers overlying the electrical nodes of the semiconductor devices. For example, at least one gate via cavity can be formed such that the bottom surface of each gate via cavity is a surface of a gate electrode (**152**, **154**), and at least one active region via cavity can be formed such that the bottom surface of each active region via cavity is a surface of an active region **130**. In one embodiment, different types of via cavities can be formed separately employing multiple combinations of photoresist layers and anisotropic etch

processes. The vertical extent of each gate via cavity, as measured from the top surface of the dielectric pillar material layer **73** to the bottom surface of the gate via cavity, can be less than the vertical distance between the top surface of the dielectric pillar material layer **73** and the topmost surface of the alternating plurality (**32**, **46**) of the insulating layers **32** and the electrically conductive layers **46**. The photoresist layer can be subsequently removed, for example, by ashing.

Another photoresist layer (not shown) can be applied over the exemplary structure, and can be lithographically patterned to form openings within the contact region **200** in which formation of contact via structures for the electrically conductive layers **46** is desired. Control gate contact via cavities can be formed through the retro-stepped dielectric material portion **65** by transfer of the pattern of the opening by an anisotropic etch. Each via cavity can vertically extend to a top surface of a respective electrically conductive layer **46**.

In addition, another photoresist layer (not shown) can be applied over the exemplary structure, and can be lithographically patterned to form openings that overlie the array of drain regions **63** in the device region **100**. Drain contact via cavities can be formed through the dielectric pillar material layer **73** and the at least one dielectric cap layer **71**.

The cavity laterally surrounded by the insulating spacer **74**, the various via cavities in the peripheral device region **200**, the control gate contact via cavities in the contact region **300**, and the drain contact via cavities in the device region **100** can be filled with a conductive material to form various contact via structures. For example, a backside contact via structure **76** can be formed in the cavity surrounded by the insulating spacer **74**. A gate contact via structure **8**G can be formed in each gate via cavity in the peripheral device region **200**. An active region via structure **8**A is formed in each active region via cavity in the peripheral device region **200**. Drain contact via structures **88** can be formed in the drain contact via cavities in the device region **100**. Further, control gate contact via structures (not shown) can be formed within each contact via cavity that extends to a top surface of the electrically conductive layers **46** in the contact region **300**. Similarly, drain contact via structures **88** can be formed to provide electrical contact to the drain regions **63**.

Referring to FIGS. **17**A and **17**B, an optional passivation layer **82** and a line-level dielectric layer **90** can be formed over the dielectric pillar material layer **73**. The optional passivation layer **82** can include a low permeability material such as silicon nitride. The thickness of the passivation layer **82** can be in a range from 3 nm to 30 nm, although lesser and greater thicknesses can also be employed. The line-level dielectric layer **90** can include silicon oxide or organosilicate glass. The thickness of the line-level dielectric layer **90** can be in a range from 30 nm to 1,000 nm, although lesser and greater thicknesses can also be employed. Control gate contact via structures **8**C can contact the electrically conductive layers **46**.

Various conductive line structures **92** can be formed in the line-level dielectric layer **90** to provide electrical contact to the various contact via structures (**76**, **8**G, **8**A, **88**, **8**C). A subset of the electrically conductive layers **46** can function as control gate electrodes for the memory stack structures **55** in the device region. Optionally, at least one subset of the electrically conductive layers **46** can be employed as at least one drain select gate electrode and/or at least one source select gate electrode.

Additional metal interconnect structures (not shown) can be optionally formed, which can include at least one dielectric material layer, at least one conductive via structure, and at least one additional conductive line structure. The additional metal interconnect structure can be formed on the top surface of the conductive line structure **92** and the line-level dielectric layer **90**.

The exemplary structure is a multilevel structure including a stack (**32**, **46**) of an alternating plurality of electrically conductive layers **46** and insulating layers **32** located over a semiconductor substrate including the semiconductor material layer **10**. An array of memory stack structures **55** can be located within memory openings through the stack (**32**, **46**).

In one embodiment, the device located on the semiconductor substrate can include a vertical NAND device located in the device region **100**, and at least one of the electrically conductive layers **46** in the stack (**32**, **46**) can comprise, or can be electrically connected to, a word line of the NAND device. The device region **100** can include a plurality of semiconductor channels (**601**, **602**). At least one end portion of each of the plurality of semiconductor channels (**601**, **602**) extends substantially perpendicular to a top surface of the semiconductor substrate. The device region **100** further includes a plurality of charge storage regions located within each memory layer **50**. Each charge storage region is located adjacent to a respective one of the plurality of semiconductor channels (**601**, **602**). The device region **100** further includes a plurality of control gate electrodes having a strip shape extending substantially parallel to the top surface of the substrate (**9**, **10**). The plurality of control gate electrodes comprise at least a first control gate electrode located in the first device level and a second control gate electrode located in the second device level. The plurality of electrically conductive layers **46** in the stack (**32**, **46**) can be in electrical contact with, or can comprise, the plurality of control gate electrodes, and extends from the device region **100** to a contact region **300** including a plurality of electrically conductive contact via structures.

In case the exemplary structure includes a three-dimensional NAND device, a stack (**32**, **46**) of an alternating plurality of word lines **46** and insulating layers **32** can be located over a semiconductor substrate. Each of the word lines **46** and insulating layers **32** is located at different levels that are vertically spaced from a top surface of the semiconductor substrate by different distances. An array of memory stack structures **55** is embedded within the stack (**32**, **46**). Each memory stack structure **55** comprises a semiconductor channel (**601**, **602**) and at least one charge storage region located adjacent to the semiconductor channel (**601**, **602**). At least one end portion of the semiconductor channel (**601**, **602**) extends substantially perpendicular to the top surface of the semiconductor substrate through the stack (**32**, **46**).

In a non-limiting illustrative example, the insulating layers **32** can comprise silicon oxide layers, the plurality of word lines **46** can comprise tungsten, ruthenium, a combination or an alloy of ruthenium and tungsten, or a combination of titanium nitride, ruthenium, and tungsten, the at least one charge storage region can comprises a tunneling dielectric, a blocking dielectric layer, and either a plurality of floating gates or a charge trapping layer located between the tunneling dielectric layer and the blocking dielectric layer. An end portion of each of the plurality of word lines **46** in a device region can comprise a control gate electrode located adjacent to the at least one charge storage region. A plurality of contact via structures contacting the word lines **46** can be located in a contact region **300**. The plurality of word lines **46** extends from the device region **100** to the contact region **300**. The backside contact via structure **76**

can be a source line that extends through a dielectric insulated trench, i.e., the backside trench **79** filled with the dielectric spacer **74** and the backside contact via structure **76**, in the stack to electrically contact the source region (not shown). The source region can be in contact with the horizontal portion of the semiconductor channel in an upper portion of the semiconductor material layer **10**.

A drain line, as embodied as a conductive line structure **92** that contacts a drain contact via structure **88**, electrically contacts an upper portion of the semiconductor channel (**601**, **602**). As used herein, a first element "electrically contacts" a second element if the first element is electrically shorted to the second element. An array of drain regions **63** contacts a respective semiconductor channel (**601**, **602**) within the array of memory stack structures **55**. A top surface of the dielectric material layer, i.e., the insulating cap layer **70**, can be coplanar with top surfaces of the drain regions **63**.

The exemplary structure of the present disclosure can comprise a three-dimensional memory device, which comprises a stack (**32**, **46**) of alternating layers comprising insulating layers **32** and electrically conductive layers **46** and located over a substrate (**9**, **10**), a memory opening extending through the alternating stack (**32**, **46**), and a memory film **50** and a semiconductor channel (**601**, **602**) located within the memory opening. Each of the electrically conductive layers **46** comprises at least a cobalt portion **48**. The electrically conductive layers **46** comprise a first control gate electrode located in a first device level, and a second control gate electrode located in a second device level that is located below the first device level.

According to another aspect of the present disclosure, a backside blocking dielectric layer can be formed in the backside recesses **43** prior to deposition of any conductive material that constitutes electrically conductive layers. In this case, the first blocking dielectric and/or the second blocking dielectric can be optionally omitted.

Referring to FIG. **18**A, a magnified region M in FIGS. **5**A and **5**B is illustrated, in which tenth exemplary electrically conductive layers are subsequently formed according to another embodiment of the present disclosure. In this case, the first blocking dielectric **501** and/or the second blocking dielectric **503** can be omitted.

In one embodiment, the first blocking dielectric **501** is omitted, and the second blocking dielectric **503**, the charge storage structure **504**, and the tunneling dielectric **505** are present within each memory film **50**. In another embodiment, the second blocking dielectric **503** is omitted, and the first blocking dielectric **501**, the charge storage structure **504**, and the tunneling dielectric **505** are present within each memory film **50**. In yet another embodiment, the first blocking dielectric **501** and the second blocking dielectric **503** are omitted, and the charge storage structure **504** and the tunneling dielectric **505** are present within each memory film **50**. Each insulating layer **32** physically contacts an outer sidewall of a respective memory film **50** around each memory opening. The omission of the first blocking dielectric **501** and/or the second blocking dielectric **503** can be effected by omitting formation of the first blocking dielectric layer **501**L and/or by omitting formation of the second blocking dielectric layer **503**L.

In still another embodiment, both the first blocking dielectric **501** and the second blocking dielectric **503** can be present within each memory film **50**. While the present disclosure is described employing an embodiment in which a first blocking dielectric **501** and a second blocking dielectric **503** are present within each memory film **50**, embodiments are expressly contemplated herein in which the first blocking dielectric **501** and/or the second blocking dielectric **503** are omitted from each memory film **50**.

The exemplary structure illustrated in FIG. **18**A can be provided by forming a stack of alternating layers comprising insulating layers **32** and sacrificial material layers **42** over a substrate **10**, and forming memory openings **49** through the stack employing the processing steps of FIG. **1**, forming a memory stack structure **55** comprising at least one charge storage structure **504**, a tunneling dielectric **505**, and a vertical semiconductor channel **60** within each memory opening **49** employing the processing steps of FIGS. **2**A-**2**F, by forming a backside trench **79** through the alternating stack of the insulating layers **32** and the sacrificial material layers **42**, and by removing the sacrificial material layers **42** by introduction of an etchant through the backside trench **79** employing the processing steps of FIGS. **5**A and **5**B. As discussed above, the removal of the sacrificial material layers **42** can be performed selective to the insulating layers **32** and the outermost material of the memory film **50**, which may be the material of the first blocking dielectric **501**, the material of the second blocking dielectric **503**, or the material of the charge storage structure **504** (which may be embodies as a continuous charge trapping material layer or discrete floating gate material portions). Thus, a sidewall of the memory film **50** is physically exposed at each backside recess **43**.

Referring to FIG. **18**B, a backside blocking dielectric layer **51** is formed directly on a sidewall of the memory stack structure **55**. Specifically, the backside blocking dielectric layer **51** is formed on the physically exposed sidewalls and horizontal surfaces of the insulating layers **32** and on the physically exposed surfaces of the memory film **50**, which can be a sidewall of the first blocking dielectric **501**, a sidewall of the second blocking dielectric **503** in case the first blocking dielectric is not present, or a sidewall of the charge storage structure **504** in case the first and second blocking dielectrics (**501**, **503**) are not present. The backside blocking dielectric layer **51** is formed within the backside recesses **43** prior to formation of electrically conductive layers.

The backside blocking dielectric layer **51** includes a dielectric material, which can be a dielectric metal oxide. In one embodiment, the backside blocking dielectric layer **51** can include a dielectric metal oxide having a dielectric constant greater than 7.9, i.e., having a dielectric constant greater than the dielectric constant of silicon nitride. Non-limiting examples of dielectric metal oxides that can be employed for the backside blocking dielectric layer **51** include aluminum oxide (Al_2O_3), hafnium oxide (HfO_2), lanthanum oxide (LaO_2), yttrium oxide (Y_2O_3), tantalum oxide (Ta_2O_5), silicates thereof, nitrogen-doped compounds thereof, alloys thereof, and stacks thereof. The backside blocking dielectric layer **51** can be deposited, for example, by chemical vapor deposition (CVD), atomic layer deposition (ALD), pulsed laser deposition (PLD), liquid source misted chemical deposition, or a combination thereof. The thickness of the backside blocking dielectric layer **51** can be in a range from 1 nm to 20 nm, although lesser and greater thicknesses can also be employed. The backside blocking dielectric layer **51** can subsequently function as a dielectric material portion that blocks leakage of stored electrical charges to control gate electrodes. In one embodiment, the backside blocking dielectric layer **51** includes aluminum oxide. In case the first blocking dielectric **501** and/or the second blocking dielectric **503** are present, the backside blocking dielectric layer **51** can comprise the same material

as, or can comprise a different material from, the material(s) of the first blocking dielectric **501** and/or the second blocking dielectric **503**.

Referring to FIG. **18**C, a metallic barrier material layer **148**L can be deposited in the backside recesses **43** and over the sidewall of the backside trench **79**. The metallic barrier material layer **148**L includes a metallic barrier material, which is a metallic material that blocks diffusion of metal elements therethrough. The metallic barrier material layer **148**L can be a conductive metallic nitride layer such as TiN, TaN, WN, or a combination or an alloy thereof. The thickness of the metallic barrier material layer **148**L can be in a range from 0.5 nm to 1.5 nm, although lesser and greater thicknesses can also be employed. The metallic barrier material layer **148**L can be deposited directly on the physically exposed surfaces of the backside blocking dielectric layer **51**, for example, by chemical vapor deposition (CVD) or atomic layer deposition (ALD). In general, the thickness of the metallic barrier material layer **148**L can be thinner if cobalt is to be subsequently deposited on the sidewalls of the metallic barrier material layer **148**L than if tungsten is to be subsequently deposited on the sidewalls of the metallic barrier material layer **148**L. A backside cavity **43'** is present in each unfilled volume of the backside recess **43**, i.e., in each volume of the backside recess **43** that is not filled with the metallic barrier material layer **148**L.

Referring to FIG. **18**D, cobalt can be deposited inside the backside cavities **43'** and in the backside trench **79** to form a cobalt layer **48**L. Deposition of the cobalt layer **48**L can be performed by chemical vapor deposition (CVD) or atomic layer deposition (ALD). Chemical vapor deposition or atomic layer deposition of cobalt employs a cobalt precursor that can be easily vaporized to leave high-purity cobalt on a surface without causing surface damage. In one embodiment, an organometallic compound with relatively high vapor pressures and good thermal stability can be employed as the cobalt precursor gas to deposit cobalt without requiring hydrogen. In a non-limiting example, bis(cyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, or bis(pentamethylcyclopentadienyl) cobalt can be employed as a cobalt precursor gas in a CVD or ALD process. Alternatively, different precursor gases (such as $Co_2(CO)_8$) can also be employed for cobalt deposition.

Since the metallic barrier material layer **148**L functions as a nucleation layer for cobalt deposition, the cobalt layer **48**L can be formed on the entire physically exposed surfaces of the metallic barrier material layer **148**L. The cobalt layer **48**L can have a substantially uniform thickness throughout. As used herein, a "substantially uniform thickness" refers to a thickness that does not deviate from the average thickness by more than 10% throughout the entire portions of an element. The duration of the cobalt deposition process can be selected such that the cobalt layer **48**L does not fill the entire volume of each backside cavity **43'** as provided after formation of the metallic barrier material layer **148**L. For example, the cobalt layer **48**L can have a thickness in a range from 2 nm to 15 nm, although lesser and greater thicknesses can also be employed. A backside cavity **43'** of a reduced volume is present between each vertically neighboring pair of insulating layers **32** after formation of the cobalt layer **48**L.

Referring to FIG. **18**E, a metallic material layer **47**L is deposited in the backside cavities **43'** and at a peripheral region of the remaining cavity in the backside trench **79**. The metallic material layer **47**L is deposited directly on the physically exposed surfaces of the cobalt layer **48**L. The metallic material layer **47**L can include any metallic material other than cobalt. In one embodiment, the metallic material layer **47**L can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material layer **47**L can comprise molybdenum, tungsten, copper, ruthenium, or titanium, or a combination thereof. In one embodiment, the metallic material layer **47**L can comprise tungsten or a tungsten-containing intermetallic alloy. The thickness of the metallic material layer **47**L can be selected such that the backside cavities **43'** are completely filled with the metallic material layer **47**L.

In one embodiment, the metallic material layer **47**L can include a material that can retard thermal migration or electromigration of cobalt atoms during subsequent processing steps and/or during operation of the memory device employing the memory stack structure **55**. In one embodiment, the metallic material layer **47**L can include a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius. Generally speaking, bulk diffusion of atoms at an elevated temperature is less for elements having high melting temperature. Thus, use of a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius can be effective in retarding thermal migration of electromigration of cobalt, which has a melting temperature of 1,495 degrees Celsius. In one embodiment, the metallic material layer **47**L can include a material selected from tungsten, molybdenum, ruthenium, and intermetallic alloys thereof. Melting points of tungsten, molybdenum, and ruthenium are 3,422 degrees Celsius, 2,623 degrees Celsius, and 2,334 degrees Celsius, respectively. In some embodiments, the metallic material layer **47**L may have horizontal divots or seams at each level between a vertically neighboring pair of insulating layers **32**.

Referring to FIG. **18**F, vertical portions of the metallic material layer **47**L, vertical portions of the cobalt layer **48**L, and vertical portions of the metallic barrier material layer **148**L are sequentially removed from the periphery of each backside trench **79** employing at least one etch process. The at least one etch process can include an isotropic etch process or an anisotropic etch process. The at least one etch process can include multiple etch chemistries that are optimized to remove the respective materials of the metallic material layer **47**L, the cobalt layer **48**L, and the metallic barrier material layer **148**L. In case at least one anisotropic etch is employed for removal of the vertical portions of the metallic material layer **47**L, the cobalt layer **48**L, and the metallic barrier material layer **148**L, remaining portions of the metallic material layer **47**L, the cobalt layer **48**L, and the metallic barrier material layer **148**L can have vertically coincident sidewalls, which may be vertically coincident with an outer sidewall of the backside blocking dielectric layer **51**. Optionally, the remaining portions of the metallic material layer **47**L, the cobalt layer **48**L, and the metallic barrier material layer **148**L may be laterally recessed toward a most proximal memory stack structure **55** from the vertical plane including the outer sidewall of the backside blocking dielectric layer **51**.

Vertical portions of the metallic material layer **47**L can be removed prior to removing the vertical portions of the cobalt layer **48**L, and vertical portions of the cobalt layer **48**L can be removed prior to removing the vertical portions of the metallic barrier material layer **148**L. Each remaining portion of the metallic barrier material layer **148**L constitutes a metallic barrier material portion **148**. Each remaining portion of the cobalt layer **48**L constitutes a cobalt portion **48**. Each remaining portion of the metallic material layer **47**L constitutes a metallic material portion **47**. Each adjoining set

of a metallic material portion **47**, a cobalt portion **48**, and a metallic barrier material portion **148** constitutes an electrically conductive layer **46**.

Within each electrically conductive layer **46**, a metallic material portion **47** is embedded in a cobalt portion **48**, and the cobalt portion **48** is embedded in a metallic barrier material portion **148**. Each metallic material portion **47** is formed directly on horizontal surfaces and a vertical surface of the cobalt portion **48** in the same electrically conductive layer **46**. Each cobalt portion **48** is formed directly on horizontal surfaces and a vertical surface of the metallic barrier material portion **148** in the same electrically conductive layer **46**. Each metallic material portion **47** comprises a metal other than cobalt, and contacts a respective cobalt portion **48**.

Each of the cobalt portions **48**, metallic barrier material portions **148**, and the backside blocking dielectric layer **51** can have a substantially uniform thickness throughout. Each metallic barrier material portion **148** can be vertically spaced from the insulating layers **32** by horizontal portions of the backside blocking dielectric layer **51**, and can be laterally spaced from the memory film **55** by a vertical portion of the backside blocking dielectric layer **51**. Each cobalt portion **48** can be vertically and laterally spaced from the backside blocking dielectric layer **51** by the metallic barrier material portion **148** within the same electrically conductive layer **46**. Each metallic material portion **47** can be vertically and laterally spaced from the metallic barrier material portion **148** in the same electrically conductive layer **46** by the cobalt portion **148** of the same electrically conductive layer **46**.

The metallic material portions **47** can include a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius. In one embodiment, the metallic material portions **47** can include a material selected from tungsten, molybdenum, ruthenium, and intermetallic alloys thereof to retard thermal migration or electromigration of cobalt in the cobalt portions **48** during subsequent processing steps and/or during operation of the semiconductor device including the memory stack structures **55**. Each metallic material portion **47** is formed directly on horizontal surfaces and a vertical surface of a respective cobalt portion **48**.

The processing steps of FIGS. **18**C-**18**F form tenth exemplary electrically conductive layers **46** within the backside recesses **43**. Each of the tenth exemplary electrically conductive layers **46** is formed by forming at least a cobalt portion **48**, and specifically, a combination of a metallic barrier material portion **148**, a cobalt portion **48**, and a metallic material portion **47**, within a respective backside recess **43**. The metallic barrier material layer **148**L is patterned to form the metallic barrier material portions **148**, and the cobalt portions **47** are formed on a respective metallic barrier material portion **148**. Each vertically neighboring pair of an electrically conductive layer **46** and an insulating layer **32** is vertically spaced from each other by a portion of the backside blocking dielectric layer **51**. Each electrically conductive layer **46** is laterally spaced form the memory stack structure **55** by a respective vertical portion of the backside blocking dielectric layer **51**.

FIGS. **19**A-**19**C illustrate a sequence of processing steps that can be employed to form eleventh exemplary electrically conductive layers **46** according to an embodiment of the present disclosure.

Referring to FIG. **19**A, the exemplary structure of FIG. **19**A can be derived from the exemplary structure of FIG. **18**D by performing an anneal at an elevated temperature. The anneal at the elevated temperature induces thermally induced self-agglomeration of the cobalt material in the cobalt layer **47**L into available volumes of the backside recesses, which are volumes defined by the metallic barrier material layer **148**L. The volumes of the backside recesses as defines by the metallic barrier material layer **148**L enable the thermally migrated cobalt material to form a shape that reduces the surface area of the thermally migrated cobalt material. Each agglomerated portion of the cobalt material forms a cobalt portion **48**, which can be provided at each level of the backside recesses, i.e., at each level between a vertically neighboring pair of insulating layers **32**.

The process parameters of the anneal process that induces self-agglomeration of the cobalt material of the cobalt layer **48**L can be optimized to avoid formation of voids in the cobalt portions **48**, while ensuring removal of the cobalt material from within the volume of the backside trench **79**. In an illustrative embodiment, the temperature of the anneal process can be selected in a range from 550 degrees Celsius to 950 degrees Celsius. In one embodiment, the temperature of the anneal process can be in a range from 650 degrees Celsius to 900 degrees Celsius, and may be in a range from 750 degrees Celsius to 850 degrees Celsius, although lower and higher temperatures can also be employed depending on duration and the ambient gas employed for the anneal process. The anneal process may be performed in vacuum, in a reduced pressure (lower than the atmospheric pressure), at atmospheric pressure, or in a pressurized environment. Optionally, an inert ambient gas such as argon or nitrogen may be employed. The cobalt portions **48** are formed by agglomeration of the material in the cobalt layer **48**L during the anneal at an elevated temperature.

Prior to agglomeration of the cobalt material, i.e., prior to the anneal process, the cobalt layer **48**L includes a pair of physically exposed horizontal surfaces and a physically exposed vertical surface within each backside recess. After agglomeration of the cobalt material in the anneal process, the cobalt portions **48** do not include any physically exposed horizontal surface. Each cobalt portion **48** can include a physically exposed convex sidewall. Without wishing to be bound by a particular theory, it is believed that the curvature of the convex sidewalls of the cobalt portions **48** is induced by surface tension of the agglomerated cobalt material. A backside cavity **43'** is present between each vertically neighboring pair of insulating layers **32** outside the convex surface of a respective cobalt portion **48**.

Referring to FIG. **19**B, a metallic material layer **47**L is deposited in the backside cavities **43'** and at a peripheral region of the remaining cavity in the backside trench **79**. The metallic material layer **47**L is deposited directly on the convex surfaces of the cobalt portions **48** and physically exposed surfaces of the metallic barrier material layer **148**L. The metallic material layer **47**L can include any metallic material other than cobalt. In one embodiment, the metallic material layer **47**L can consist essentially of a single elemental metal or an intermetallic alloy of at least two elemental metals. For example, the metallic material layer **47**L can comprise molybdenum, tungsten, copper, ruthenium, or titanium, or a combination thereof. In one embodiment, the metallic material layer **47**L can comprise tungsten or a tungsten-containing intermetallic alloy. The thickness of the metallic material layer **47**L can be selected such that the backside cavities **43'** are completely filled with the metallic material layer **47**L.

In one embodiment, the metallic material layer **47**L can include a material that can retard thermal migration or electromigration of cobalt atoms during subsequent process-

ing steps and/or during operation of the memory device employing the memory stack structure **55**. In one embodiment, the metallic material layer **47**L can include a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius. In one embodiment, the metallic material layer **47**L can include a material selected from tungsten, molybdenum, ruthenium, and intermetallic alloys thereof. In some embodiments, the metallic material layer **47**L may have horizontal divots or seams at each level between a vertically neighboring pair of insulating layers **32**.

Referring to FIG. **19**C, vertical portions of the metallic material layer **47**L and vertical portions of the metallic barrier material layer **148**L are sequentially removed from the periphery of each backside trench **79** employing at least one etch process. The at least one etch process can include an isotropic etch process or an anisotropic etch process. The at least one etch process can include multiple etch chemistries that are optimized to remove the respective materials of the metallic material layer **47**L and the metallic barrier material layer **148**L. In case at least one anisotropic etch is employed for removal of the vertical portions of the metallic material layer **47**L and the metallic barrier material layer **148**L, remaining portions of the metallic material layer **47**L and the metallic barrier material layer **148**L can have vertically coincident sidewalls, which may be vertically coincident with an outer sidewall of the backside blocking dielectric layer **51**. Alternatively, the remaining portions of the metallic material layer **47**L can be laterally recessed toward a most proximal memory stack structure **55** from the vertical plane including the outer sidewall of the backside blocking dielectric layer **51**.

Vertical portions of the metallic material layer **47**L can be removed prior to removing the vertical portions of the metallic barrier material layer **148**L. Each remaining portion of the metallic barrier material layer **148**L constitutes a metallic barrier material portion **148**. Each remaining portion of the metallic material layer **47**L constitutes a metallic material portion **47**. Each adjoining set of a metallic material portion **47**, a cobalt portion **48**, and a metallic barrier material portion **148** constitutes an electrically conductive layer **46**.

Within each electrically conductive layer **46**, the metallic material portion **47** is embedded within the metallic barrier material portion **147**, and the cobalt portion **48** is embedded in the metallic barrier material portion **148**. The cobalt portion **48** is more proximal to the most proximate memory film **50** than the metallic material portion **47** is to the most proximate memory film **50**. Each metallic material portion **47** is formed directly on horizontal surfaces the metallic barrier material portion **148** within the same electrically conductive layer **46**, and directly on a convex sidewall surface of the cobalt portion **48** in the same electrically conductive layer **46**. Each cobalt portion **48** is formed directly on horizontal surfaces and a vertical surface of the metallic barrier material portion **148** in the same electrically conductive layer **46**. Each metallic material portion **47** comprises a metal other than cobalt, and contacts a respective cobalt portion **48**.

Each of the metallic barrier material portions **148** and the backside blocking dielectric layer **51** can have a substantially uniform thickness throughout. Each metallic barrier material portion **148** can be vertically spaced from the insulating layers **32** by horizontal portions of the backside blocking dielectric layer **51**, and can be laterally spaced from the memory film **55** by a vertical portion of the backside blocking dielectric layer **51**. Each cobalt portion **48** can be vertically and laterally spaced from the backside blocking dielectric layer **51** by the metallic barrier material portion **148** within the same electrically conductive layer **46**. Each metallic material portion **47** can be laterally spaced from the metallic barrier material portion **148** in the same electrically conductive layer **46** by the cobalt portion **148** of the same electrically conductive layer **46**. Each metallic material portion **47** contacts two horizontal surfaces of the metallic barrier material portion **148** within the same electrically conductive layer **46**.

The metallic material portions **47** can include a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius. In one embodiment, the metallic material portions **47** can include a material selected from tungsten, molybdenum, ruthenium, and intermetallic alloys thereof to retard thermal migration or electromigration of cobalt in the cobalt portions **48** during subsequent processing steps and/or during operation of the semiconductor device including the memory stack structures **55**. Each metallic material portion **47** is formed directly a convex outer sidewall of a respective cobalt portion **48**.

Referring to FIG. **19**D, an alternate embodiment of the eleventh exemplary electrically conductive layers **46** is illustrated. The alternate embodiment of the eleventh exemplary electrically conductive layers **46** according to an embodiment of the present disclosure can be derived from the exemplary structure of FIG. **19**B by modifying an etch process employed to remove vertical portions of the metallic material layer **47**L and the vertical portions of the metallic barrier material layer **148**L. In case horizontal divots are present on the outer surface of the metallic material layer **47**L at the processing step of FIG. **19**B and if an isotropic etch process is employed to remove vertical portions of the metallic material layer **47**L, the metallic material portions **47** (i.e., the remaining portions of the metallic material layer **47**L after removal of the vertical portions thereof) can have a concave outer surface. In this case, each metallic material portion **47** can have a concave inner sidewall contacting a convex outer sidewall of a respective cobalt portion **47**, a concave outer sidewall that is physically exposed at the processing step of FIG. **19**D and is subsequently contacted by a convex portion of a sidewall of an insulating spacer, and two horizontal surfaces that contact a bottom surface and a top surface of the metallic barrier material portion **147** within the same electrically conductive layer **46**.

The processing steps of FIG. **19A**-**19**C or **19**A, **19**B, and **19**D form eleventh exemplary electrically conductive layers **46** within the backside recesses **43**. Each of the eleventh exemplary electrically conductive layers **46** is formed by forming at least a cobalt portion **48**, and specifically, a combination of a metallic barrier material portion **148**, a cobalt portion **48**, and a metallic material portion **47**, within a respective backside recess **43**. The metallic barrier material layer **148**L is patterned to form the metallic barrier material portions **148**, and the cobalt portions **47** are formed on a respective metallic barrier material portion **148**. Each vertically neighboring pair of an electrically conductive layer **46** and an insulating layer **32** is vertically spaced from each other by a portion of the backside blocking dielectric layer **51**. Each electrically conductive layer **46** is laterally spaced form the memory stack structure **55** by a respective vertical portion of the backside blocking dielectric layer **51**.

Vertical portions of the metallic material layer **47**L are removed to form metallic material portions **47** after migration of the material of the vertical portions of the cobalt layer **48**L during the anneal process that forms the cobalt portions **48**. Each metallic material portion **47** is formed on a convex surface of a respective cobalt portion **48** and horizontal

surfaces of metallic barrier material portions **148**, which are horizontal portions of the metallic barrier material layer **148**L. Each vertically neighboring pair of an electrically conductive layer **46** and an insulating layer **32** is vertically spaced from each other by a portion of the backside blocking dielectric layer **51**, and each electrically conductive layer **46** is laterally spaced form a most proximal memory stack structure **55** by a respective vertical portion of the backside blocking dielectric layer **51**.

FIGS. **20**A-**20**C illustrate various modifications of the exemplary structure of FIG. **18**F according to embodiments of the present disclosure. The structure of FIG. **20**A can be derived from the structure of FIG. **18**F by omitting formation of the first blocking dielectric **501**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the second blocking dielectric **503** at each level of the electrically conductive layers **46**. The structure of FIG. **20**B can be derived from the structure of FIG. **18**F by omitting formation of the second blocking dielectric **503**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the first blocking dielectric **501** at each level of the electrically conductive layers **46**. The structure of FIG. **20**C can be derived from the structure of FIG. **18**F by omitting formation of the first blocking dielectric **501** and the second blocking dielectric **503**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the charge storage structure **504** at each level of the electrically conductive layers **46**.

FIGS. **21**A-**21**C illustrate various modifications of the exemplary structure of FIG. **19**C according to embodiments of the present disclosure. The structure of FIG. **21**A can be derived from the structure of FIG. **19**C by omitting formation of the first blocking dielectric **501**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the second blocking dielectric **503** at each level of the electrically conductive layers **46**. The structure of FIG. **21**B can be derived from the structure of FIG. **19**C by omitting formation of the second blocking dielectric **503**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the first blocking dielectric **501** at each level of the electrically conductive layers **46**. The structure of FIG. **21**C can be derived from the structure of FIG. **19**C by omitting formation of the first blocking dielectric **501** and the second blocking dielectric **503**. In this case, the backside blocking dielectric layer **51** contacts an outer sidewall of the charge storage structure **504** at each level of the electrically conductive layers **46**.

The various electrically conductive layers **46** illustrated in FIGS. **18**F, **19**C, **19**D, **20**A-**20**C, and **21**A-**21**C can be incorporated into the exemplary structure illustrated in FIGS. **15**, **16**, **17**A, and **17**B to provide a three-dimensional memory device. Such as three-dimensional memory device can include a stack of alternating layers comprising insulating layers **32** and electrically conductive layers **46** and located over a substrate (**9**, **10**, **63**); a memory opening **49** extending through the alternating stack (**32**, **46**); and a memory stack structure **55** comprising at least one charge storage structure **504**, a tunneling dielectric **505**, and a vertical semiconductor channel **60** and is located within the memory opening **49**. Each of the electrically conductive layers **46** can comprises at least a cobalt portion **48**.

In one embodiment, a backside blocking dielectric layer **51** can be provided, which includes horizontal portions located between each vertically neighboring pair of an insulating layer **32** and an electrically conductive layer **46** within the stack of alternating layers (**32**, **46**). In one embodiment, the backside blocking dielectric layer **51** can further include vertical portions adjoining a respective vertically neighboring pair of horizontal portions of the backside blocking dielectric layer **51** and contacting a sidewall of the memory stack structure **55**. In one embodiment, each of the electrically conductive layers **46** can further include a metallic barrier material portion **148** contacting a respective pair of horizontal portions of the backside blocking dielectric layer **51**.

In one embodiment, the three-dimensional memory device can include a backside contact via structure **76** extending through a backside trench **79** in the stack (**32**, **46**), electrically isolated from the electrically conductive layers **46** (for example, by an insulating spacer **74**), and contacting a source region **61** located in the substrate (**9**, **10**, **63**). A proximal sidewall of each cobalt portion **48** can be laterally spaced from a respective vertical portion of the backside blocking dielectric layer **51** by a vertical portion of a respective metallic barrier material portion **148**. Each cobalt portion **48** can be laterally recessed from the backside trench **79**.

In one embodiment, each cobalt portion **48** can contact a surface of a respective metallic barrier material portion **148**. In one embodiment, each cobalt portion **48** can contact a pair of horizontal surfaces of the respective metallic barrier material portion **148** and an outer sidewall of the respective metallic barrier material portion **148** as illustrated in FIGS. **18**F and **20**A-**20**C.

In one embodiment, each of the electrically conductive layers **46** can include a metallic material portion **47** containing a material other than cobalt and contacting a respective cobalt portion. In one embodiment, each of the electrically conductive layers **46** can include a metallic barrier material portion **148** contacting the backside blocking dielectric layer **51** and the cobalt portion **48**. In one embodiment, the metallic material portion **47** can be laterally and vertically spaced from the metallic barrier material portion **148** by the cobalt portion **48** as illustrated in FIGS. **18**F and **20**A-**20**C.

In one embodiment, the metallic material portion **47** can contact the metallic barrier material portion **148** as illustrated in FIGS. **19**C, **19**D, and **21**A-**21**C. In one embodiment, a concave surface of the metallic material portion **47** can contact a convex surface of the cobalt portion **48**.

In one embodiment, the metallic material portion **47** can include a material having a melting point at 1 atmospheric pressure of greater than 2,000 degrees Celsius. In one embodiment, the metallic material portion **47** can include a material selected from tungsten, molybdenum, ruthenium, and intermetallic alloys thereof.

In one embodiment, the three-dimensional memory device can include a vertical NAND device located in a device region. The electrically conductive layers **46** comprise, or are electrically connected to, a respective word line of the vertical NAND device. The device region can include a plurality of semiconductor channels **60**, wherein at least one end portion of each of the plurality of semiconductor channels **60** extends substantially perpendicular to a top surface of the substrate (**9**, **10**). The device region can further include a plurality of charge storage regions (as embodied as portions of the charge storage structure **504** located at levels of the electrically conductive layers **46**). Each charge storage region can be located adjacent to a respective one of the plurality of semiconductor channels **60**. The device region can include a plurality of control gate electrodes (as embodies as portions of the electrically conducive layers **46**) having a strip shape extending substantially parallel to the top surface of the substrate (**9**, **10**).

In one embodiment, the plurality of control gate electrodes can include at least a first control gate electrode located in a first device level and a second control gate electrode located in a second device level. The electrically conductive layers **46** in the stack (**32**, **46**) can be in electrical contact with the plurality of control gate electrode, and can extend from the device region to a contact region including the plurality of electrically conductive via connections as embodied as control gate contact via structures **8**C illustrated in FIG. **17**B. The substrate (**9**, **10**) can comprise a silicon substrate containing a driver circuit for the vertical NAND device.

Referring to FIG. **22**A, twelfth exemplary electrically conductive layers according to an embodiment of the present disclosure can be derived from the fifth exemplary structure of FIG. **10**A. To provide the fifth exemplary structure of FIG. **10**A, a backside trench **79** vertically extending through the alternating stack (**32**, **42**) can be formed, and the backside recesses **43** can be formed by providing an etchant that etches the sacrificial material layers **42** through the backside trench **79**. A metallic barrier material layer **148**L can be formed as a first continuous material layer in the backside trench **79** and the backside recesses **43** employing the processing steps of FIG. **6**A. A metallic material layer **48**L can be deposited as a second continuous material layer in the backside trench **79** and the backside recesses **43** employing the processing steps of FIG. **7**A. In one embodiment, the metallic barrier material layer **148**L comprises a conductive metal nitride, and the metallic material layer **47**L consists essentially of tungsten.

Portions of the metallic barrier material layer **148**L and the metallic material layer **48**L can be removed from inside the backside trench **79** and from regions of the backside recesses **43** that are proximal to the backside trench **79** by performing the processing steps of FIG. **10**A. Remaining portions of the first and second continuous material layers constitute the metallic barrier material portions **148** and the metallic material portions **47**, respectively.

A combination of a metallic barrier material portion **148** and a metallic material portion **47** is formed within each portion of a backside recess that is proximal to a memory stack structure **55**. Each of the metallic barrier material portions **148** and the metallic material portions **47** can have a substantially vertical sidewall that is physically exposed to an unfilled portion of a respective backside recess **43**. A distal sidewall of each metallic material portion **47** and a distal sidewall of each metallic barrier material portion **148** can be more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. A proximal sidewall of each metallic material portion **47** can contact an outer sidewall of a metallic barrier material portion **148**. A backside cavity **43'** is present between each combination of a metallic barrier material portion **148** and a metallic material portion **47** and the backside trench **79**.

Referring to FIG. **22**B, ruthenium can be deposited inside the backside cavities **43'** to form ruthenium portions **248**. In one embodiment, ruthenium can be grown by a selective deposition process that deposits ruthenium from surfaces of the metallic barrier material portions **148** and the metallic material portions **47**, and does not deposit ruthenium on dielectric surfaces. Selective deposition of ruthenium can be performed by atomic layer deposition (ALD), which is a selective atomic layer deposition process.

In one embodiment, the selective atomic layer deposition process alternately provides a ruthenium-containing precursor gas such as RuO_4 as a reactant and H_2 as a reduction gas into a process chamber including the exemplary structure. The ruthenium-containing precursor gas and the reduction gas are alternately provided into the backside recesses to grow ruthenium from the surfaces of the metallic barrier material portions **148** and the metallic material portions **47**. When RuO_4 is flowed into the process chamber, RuO_4 can be catalytically converted into RuO_2 on surfaces of the metallic material portions **47** and the metallic barrier material portions **148** to form a RuO_2 monolayer, i.e., a single layer of RuO_2.

During the initial cycle of the RuO_4 flow, the catalytic conversion of RuO_4 into RuO_2 occurs only on the surfaces of the metallic material portions **47** and the metallic barrier material portions **148** where the metallic materials of the surfaces of the metallic material portions **47** and the metallic barrier material portions **148** function as catalysts. A reducing agent such as hydrogen gas can be subsequently flowed into the processing chamber to convert the RuO_2 monolayer into a ruthenium monolayer.

Once a ruthenium monolayer is formed on the surfaces of the metallic material portions **47** and the metallic barrier material portions **148**, the ruthenium layer can function as catalyst for additional cycles of RuO_2 monolayer formation and reduction of each RuO_2 monolayer into an additional ruthenium monolayer. Generally, RuO_4 forms a monolayer of RuO_2 on the surfaces of the metallic barrier material portions **148** and the metallic material portions **47** and on surfaces of preexisting ruthenium material. Each monolayer of RuO_2 that is formed during a respective RuO_4 flow cycle is reduced by H_2 into a layer of elemental ruthenium during the selective atomic layer deposition process.

Incubation delay during the catalytic formation of RuO_2 monolayers depends on the effectiveness of the underlying surface as the catalyst for conversion of RuO_4 gas molecules into RuO_2. A silicon oxide surface provides a longer incubation time for formation of an RuO_2 monolayer thereupon, while tungsten or other metals and metallic nitride materials (such as TiN) have shorter incubation times. The incubation time for silicon surfaces is longer than the incubation time for surfaces of metallic materials, and is shorter than the incubation time for surfaces of silicon oxide. In case the insulating layers **32** include silicon oxide, the duration of exposure to the RuO_4 gas during each step for formation of an RuO_2 monolayer can be longer than the incubation time for the metallic materials of the metallic material portions **47** and the metallic barrier material portions **148**, and shorter than the incubation time for silicon oxide and/or shorter than the incubation time for silicon. In this case, selective growth of ruthenium only from the surfaces of the metallic material portions **47** and the metallic barrier material portions **148** can be achieved, while ruthenium does not grow from surfaces of the insulating layers **32**. Ruthenium portions **248** are formed by selective deposition of ruthenium.

The number of cycles of the ruthenium deposition process can be selected such that the metallic material portions **47**, the metallic barrier material portions **148**, and the ruthenium portions **248** fill a predominant (e.g., greater than 50 volume percent) portion of each backside recess **43**. In one embodiment, the number of cycles of the ruthenium deposition process can be selected such that outer sidewalls of the ruthenium portions **248** are laterally offset inward (i.e., toward a most proximal memory stack structure **55**) from a sidewall of a most proximal backside trench **79**. Alternatively, the number of cycles of the ruthenium deposition process can be selected such the ruthenium portions **248** protrude into the most proximal backside trench **79**, and a

subsequent anisotropic etch process and/or an isotropic etch process laterally recesses outer sidewalls of the ruthenium portions **248**.

A combination of a metallic barrier material portion **148**, a ruthenium portion **248** contacting horizontal surfaces of a pair of insulating layers **32**, and a metallic material portion **47** encapsulated by the metallic barrier material portion **148** and the ruthenium portion **248** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a ruthenium portion **248**, a metallic material portion **47** including a metallic material other than ruthenium (e.g., tungsten), and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Optionally, an anisotropic etch or an isotropic etch can be performed to remove regions of the ruthenium portions **248** inside backside trench **79**. In this case, the ruthenium portions **248** can have sidewalls that are vertically coincident with sidewalls of the insulating layers **32** around the backside trench **79**. Optionally, the ruthenium portions **248** may be laterally recessed from the sidewall of the backside trench **79**, for example, by a recess etch. Each ruthenium portion **248** contacts a horizontal surface of an overlying dielectric layer (e.g., an overlying insulating layer **32**) and a horizontal surface of an underlying dielectric layer (e.g., an underlying insulating layer **32**). Each ruthenium portion **248** is formed directly on a sidewall of a respective metallic barrier material portion **148** and a sidewall of the metallic material portion **47**.

In one embodiment, the ruthenium portions **248** may have a distal sidewall that is as distal as, or more distal than, the sidewalls of the insulating layers **32** that face the backside trench **79**. In one embodiment, the ruthenium portions **248** can include a respective vertical sidewall, a convex upper surface adjoined to the vertical sidewall and to an overlying insulating layer **32**, and a convex lower surface adjoined to the vertical sidewall and to an underlying insulating layer **32**.

Subsequently, the processing steps of FIG. **16** can be performed. FIG. **22**C illustrates the region of FIGS. **22**A and **22**B after formation of an insulating spacer **74**. Distal sidewalls (i.e., outer sidewalls) of the ruthenium portions **248** contact an outer sidewall of the insulating spacer **74**. In case the distal sidewalls of the ruthenium portions **248** laterally protrude into the backside trench **79** at the processing step of FIG. **22**B, the insulating spacer **74** can have a laterally undulating surface that is laterally recessed inward at each level of the ruthenium portions **248**. If the ruthenium portions **248** include convex surfaces adjoined to a respective vertical surface, the insulating spacer **74** can have concave surfaces adjoined to a respective laterally recessed surface.

In another embodiment, a backside blocking dielectric layer **51** (as illustrated in FIG. **21**A) can be formed in the backside recesses prior to formation of the metallic barrier material layer **148**L and the metallic material layer **47**L. If the processing steps of FIGS. **22**A-**22**C are subsequently performed, a structure derived from the structure of FIG. **22**C can be formed, in which the backside blocking dielectric layer **51** is present at locations of each interface between the combination of the memory stack structures **55** and the insulating layers **32** and the combination of the electrically conductive layers (**148**, **47**, **248**) and the insulating spacer **74**.

Referring to FIG. **23**A, thirteenth exemplary electrically conductive layers according to an embodiment of the present disclosure can be derived from structure illustrated in FIG. **18**C (that can be employed to form the tenth exemplary conductive layers). The exemplary structure of FIG. **23**A can be the same as the exemplary structure of FIG. **18**C. Specifically, a metallic barrier material layer **148**L can be formed as a first continuous material layer in the backside trench **79** and the backside recesses **43** employing the processing steps of FIG. **6**A. In one embodiment, the metallic barrier material layer **148**L comprises a conductive metal nitride.

Referring to FIG. **23**B, the processing steps of FIG. **8**A can be performed to form a metallic material layer **47**L on the metallic barrier material layer **148**L. The metallic material layer **47**L can have the same composition as, and can be formed by the same method as, in the previously described embodiments. The metallic material layer **47**L can be deposited as a second continuous material layer in the backside trench **79** and the backside recesses **43** employing the processing steps of FIG. **7**A. In one embodiment, the metallic material layer **47**L consists essentially of tungsten.

Referring to FIG. **23**C, the processing steps of FIG. **10**A can be performed to laterally etch portions of the metallic material layer **47**L and the metallic barrier material layer **148**L. Etching of the metallic material layer **47**L and the metallic barrier material layer **148**L can be selective to the material of the backside blocking dielectric layer **51**. A metallic material portion **47** and a metallic barrier material portion **148** are formed within a region of each backside recess **43** that is proximal to a memory stack structure **55**. A combination of a metallic barrier material portion **148** and a metallic material portion **47** is formed within each portion of a backside recess that is proximal to a memory stack structure **55**. A distal sidewall of each metallic material portion **47** and a distal sidewall of each metallic barrier material portion **148** can be more proximal to the memory film **50** than the sidewall of the backside trench **79** is to the memory film **50** by the lateral recess distance lrd. A proximal sidewall of each metallic material portion **47** can contact an outer sidewall of a metallic barrier material portion **148**. A backside cavity **43'** is present between each combination of a metallic barrier material portion **148** and a metallic material portion **47** and the backside trench **79**.

Referring to FIG. **23**D, the processing steps of FIG. **6**C can be performed to form cobalt portions **48** within an unfilled volume of each backside recess **43**. Cobalt can be selectively deposited inside the backside cavities to form cobalt portions **48**, while suppressing growth of cobalt from dielectric surfaces such as the surfaces of the backside blocking dielectric layer **51**. Deposition of cobalt can be performed by chemical vapor deposition (CVD) or atomic layer deposition (ALD). Chemical vapor deposition or atomic layer deposition of cobalt employs a cobalt precursor that can be easily vaporized to leave high-purity cobalt on a surface without causing surface damage. In one embodiment, an organometallic compound with relatively high vapor pressures and good thermal stability can be employed as the cobalt precursor gas to deposit cobalt without requiring hydrogen. In a non-limiting example, bis(cyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, bis(ethylcyclopentadienyl)cobalt, or bis(pentamethylcyclopentadienyl) cobalt can be employed as a cobalt precursor gas in a CVD or ALD process. Alternatively, different precursor gases (such as $Co_2(CO)_8$) can also be employed for cobalt deposition.

Cobalt grows from physically exposed surfaces of the metallic barrier material portions **148** and the metallic material portions **47**. Cobalt may be selectively nucleated on

metallic surfaces including the outer sidewalls of the metallic barrier material portions **148** and the metallic material portions **47**. Thus, cobalt portions **48** can grow selectively only from the surfaces of the metallic barrier material portions **148** and from the surfaces of the metallic material portions **47**, and do not grow from the surfaces of the backside blocking dielectric layer **51**. As such, the cobalt deposition process is a selective deposition process that proceeds from the surfaces of the metallic barrier material portions **148** and the metallic material portions **47**, while cobalt does not grow from the surfaces of the backside blocking dielectric layer **51**. Each cobalt portion **48** can be formed directly on an outer sidewall a respective metallic barrier material portion **148** including a pair of vertical sidewalls of the respective metallic barrier material portion **148** that are vertically spaced apart by a respective metallic material portion **47**. Further, each cobalt portion **48** can be formed directly on an outer sidewall of a respective metallic material portion **47**. Each deposited portion of cobalt constitutes one of the cobalt portions **48**.

In one embodiment, the duration of the cobalt deposition process can be selected such that the cobalt portions **48** completely fill the backside cavities **43'**. In one embodiment, a convex sidewall of each cobalt portion **48** can protrude into the backside trench **79** due to the selective nature of the cobalt deposition process. A combination of a metallic barrier material portion **148**, a metallic material portion **47** embedded within the metallic barrier material portion **148**, and a cobalt portion **48** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can consist of a cobalt portion **48**, a metallic barrier material portion **148**, and a metallic material portion **47**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces and vertical surfaces of the backside blocking dielectric layer **51**.

The metallic material portions **47**, the metallic barrier material portions **148**, and the cobalt portions **48** fill a predominant portion, or the entirety, of each backside recess **43**. In one embodiment, the cobalt portions can be formed with a respective convex surface that protrudes out of volumes of the backside recesses **43** and into the backside trench **79**. In other words, the cobalt portions **48** as formed may protrude into the most proximal backside trench **79**. In one embodiment, the cobalt portions **48** can be formed with a respective convex surface that is physically exposed to remaining portions of the backside recesses.

In one embodiment, the electrically conductive layers **46** can be employed as is, and subsequent processing steps of FIG. **16** can be performed. Alternatively, an anneal process may be optionally performed to induce agglomeration of the cobalt portions **48** so that outer sidewalls of the cobalt portions develop a convex shape that minimizes surface tension and to reduce metal migration in subsequent processing steps.

FIG. **23**E illustrates the region of FIG. **23**D after formation of an insulating spacer **74**. Distal sidewalls (i.e., outer sidewalls) of the cobalt portions **48** contact an outer sidewall of the insulating spacer **74**. In case the distal sidewalls of the cobalt portions **48** laterally protrude into the backside trench **79** at the processing step of FIG. **23**D, the insulating spacer **74** can have a laterally undulating surface that is laterally recessed inward at each level of the cobalt portions **48**. If the cobalt portions **48** include convex surfaces adjoined to a respective vertical surface, the insulating spacer **74** can have concave surfaces adjoined to a respective laterally recessed surface.

Referring to FIG. **24**A, fourteenth exemplary electrically conductive layers according to an embodiment of the present disclosure can be derived from structure illustrated in FIG. **23**C. The exemplary structure of FIG. **24**A can be the same as the exemplary structure of FIG. **23**C.

Referring to FIG. **24**B, the processing steps of FIG. **22**B can be performed to form ruthenium portions **248**. Ruthenium can be deposited inside the backside cavities **43'** to form ruthenium portions **248**. In one embodiment, ruthenium can be grown by a selective deposition process that deposits ruthenium from surfaces of the metallic barrier material portions **148** and the metallic material portions **47**, and does not deposit ruthenium on dielectric surfaces such as the surfaces of the backside blocking dielectric layer **51**.

Selective deposition of ruthenium can be performed by the same selective atomic layer deposition process as the processing steps of FIG. **22**B. In this case, the physically exposed surfaces of the backside blocking dielectric layer **51** are dielectric surfaces from which ruthenium does not grow. The incubation time for RuO_2 on aluminum oxide material of the backside blocking dielectric layer **51** is longer than the incubation time on the metallic material portions **47** and the incubation time on the metallic barrier material portions **148**.

A combination of a metallic barrier material portion **148**, a ruthenium portion **248** contacting horizontal surfaces of a pair of insulating layers **32**, and a metallic material portion **47** encapsulated by the metallic barrier material portion **148** and the ruthenium portion **248** constitutes an electrically conductive layer **46** at each level. Thus, each electrically conductive layer **46** can comprise a ruthenium portion **248**, a metallic material portion **47** including a metallic material other than ruthenium, and a metallic barrier material portion **148**. Each electrically conductive layer **46** can be formed directly on horizontal surfaces of the insulating layers **32** and directly on an outer sidewall of the memory film **50**. Optionally, an anisotropic etch or an isotropic etch can be performed to remove regions of the ruthenium portions **248** inside backside trench **79**. In this case, the ruthenium portions **248** can have sidewalls that are vertically coincident with sidewalls of the insulating layers **32** around the backside trench **79**. Optionally, the ruthenium portions **248** may be laterally recessed from the sidewall of the backside trench **79**, for example, by a recess etch. Each ruthenium portion **248** contacts a horizontal surface of an overlying dielectric layer (e.g., an overlying portion of the backside blocking dielectric layer **51**) and a horizontal surface of an underlying dielectric layer (e.g., an underlying portion of the backside blocking dielectric layer **51**).

FIG. **24**C illustrates the region of FIG. **24**B after formation of an insulating spacer **74**. Distal sidewalls (i.e., outer sidewalls) of the ruthenium portions **248** contact an outer sidewall of the insulating spacer **74**. In case the distal sidewalls of the ruthenium portions **248** laterally protrude into the backside trench **79** at the processing step of FIG. **24**B, the insulating spacer **74** can have a laterally undulating surface that is laterally recessed inward at each level of the ruthenium portions **248**. If the ruthenium portions **248** include convex surfaces adjoined to a respective vertical surface, the insulating spacer **74** can have concave surfaces adjoined to a respective laterally recessed surface.

Each of the twelfth, thirteenth, and fourteenth exemplary conductive layers can be incorporated into the exemplary structure of FIGS. **17**A and **17**B, or variations thereof. Such exemplary structures can include a three-dimensional memory device comprising: a stack of alternating layers (**32**, **46**) comprising insulating layers **32** and electrically conduc-

tive layers **46** and located over a substrate (**9**, **10**); a memory opening extending through the alternating stack (**32**, **46**); and a memory stack structure **55** located within the memory opening. Each of the electrically conductive layers **46** comprises: a metallic barrier material portion **148**; a metallic material portion **47** that is spaced from the memory stack structure **55** by a vertical portion of the metallic barrier material portion **148**, and spaced from the insulating layers **32** by horizontal portions of the metallic barrier material portion **148**; and a metal portion (**48** or **248**) contacting a sidewall of the metallic barrier material portion **148** and a sidewall of the metallic material portion **47** and an overlying insulating surface (which may be a surface of an overlying insulating layer **32** or a surface of a backside blocking dielectric layer **51**) and an underlying insulating surface (which may be a surface of an underlying insulating layer **32** or a surface of the backside blocking dielectric layer **51**). The metal portion (**48** or **248**) comprises a material selected from cobalt and ruthenium.

In one embodiment, all surfaces of the metallic material portion **47** directly contact a surface of the metallic barrier material portion **148** or a surface of the metal portion (**48** or **248**), and the metallic material portion **47** does not contact the overlying or the underlying insulating surface (e.g., the surfaces of the insulating layers **32** or of the backside blocking dielectric **51**). In one embodiment, the metallic barrier material portion **148** comprises a conductive metallic nitride material (such as TiN, TaN, or WIN), and the metallic material portion **47** consists essentially of elemental tungsten.

A backside trench **79** vertically extending through the alternating stack (**32**, **46**) can be provided, which can contain an insulating spacer **74** at a periphery thereof. An inner sidewall of the metal portion (**48** or **248**) directly contacts the sidewall of the metallic barrier material portion **148** and the sidewall of the metallic material portion **47**, and at least a portion of an interface between an outer sidewall of the metal portion (**48** or **248**) and the insulating spacer **74** protrudes farther outward from the memory stack structure **55** than interfaces between sidewalls of the insulating layers **32** and the insulating spacer **74**.

In one embodiment, the metal portion **248** can consist essentially of ruthenium, and the interface between the outer sidewall of the metal portion **248** and the insulating spacer can include a laterally undulating surface. The outer sidewall of each metal portion **48** can include a vertical portion and convex portions.

In one embodiment, the metal portion **48** consists essentially of cobalt, and a convex sidewall of the metal portion **48** contacts a concave sidewall of the insulating spacer **74** at the interface between the outer sidewall of the metal portion **48** and the insulating spacer **74**.

In one embodiment, the memory stack structure **55** can comprise: a charge storage layer **504**; a tunneling dielectric **506** located on an inner sidewall of the charge storage layer **504**; and a vertical semiconductor channel **60** contacting an inner sidewall of the tunneling dielectric **506**, wherein a blocking dielectric layer (**501**, **503**, **51**) is located within the memory opening on an outer sidewall of the charge storage layer **504** or between each vertically neighboring pair of an electrically conductive layer **46** among the electrically conductive layers **46** and an insulating layer **32** among the insulating layers **32**.

In one embodiment, the metallic barrier material portion **148** comprises a vertical portion contacting a sidewall of the blocking dielectric layer **51**, an upper horizontal portion overlying the metallic material portion **47** and adjoined to the vertical portion and contacting the metal portion (**48** or **248**), and a lower horizontal portion underlying the metallic material portion **47** and adjoined to the vertical portion and contacting the metal portion (**48** or **248**).

In one embodiment, each of the metal portion (**48** or **248**) and the metallic barrier material portion **148** contacts a bottom surface of an overlying insulating layer **32** and a top surface of an underlying insulating layer **32**. The metallic material portion **47** does not contact the overlying insulating layer **32** or the underlying insulating layer **32**.

In another embodiment, a backside blocking dielectric layer **51** can be located between each vertically neighboring pair of an electrically conductive layer **46** and an insulating layer **32**, wherein each of the metal portion (**48** or **248**) and the metallic barrier material portion **148** contacts a bottom surface of an overlying portion of the backside blocking dielectric layer **51** and a top surface of an underlying portion of the backside blocking dielectric layer **51**. The metallic material portion **47** does not contact the backside blocking dielectric layer **51**.

The twelfth through fourteenth exemplary electrically conductive layers **46** can utilize a larger volume of the backside recesses **43** and peripheral portions of the volume of each backside trench **79** to provide a low resistivity word line.

Although the foregoing refers to particular preferred embodiments, it will be understood that the disclosure is not so limited. It will occur to those of ordinary skill in the art that various modifications may be made to the disclosed embodiments and that such modifications are intended to be within the scope of the disclosure. Where an embodiment employing a particular structure and/or configuration is illustrated in the present disclosure, it is understood that the present disclosure may be practiced with any other compatible structures and/or configurations that are functionally equivalent provided that such substitutions are not explicitly forbidden or otherwise known to be impossible to one of ordinary skill in the art. All of the publications, patent applications and patents cited herein are incorporated herein by reference in their entirety.

What is claimed is:

1. A three-dimensional memory device, comprising:

a stack of alternating layers comprising insulating layers and electrically conductive layers located over a substrate;

a memory opening extending through the alternating stack; and

a memory stack structure located within the memory opening; and

wherein each of the electrically conductive layers comprises:

a metallic barrier material portion;

a metallic material portion that consists essentially of a first metal and is spaced from the memory stack structure by a vertical portion of the metallic barrier material portion, and spaced from the insulating layers by horizontal portions of the metallic barrier material portion; and

a metal portion contacting a distal sidewall of the metallic barrier material portion, a distal sidewall of the metallic material portion, an overlying insulating surface, and an underlying insulating surface, wherein the metal portion consists essentially of cobalt that is different from the first metal.

2. The three-dimensional memory device of claim **1**, wherein all surfaces of the metallic material portion directly contact a surface of the metallic barrier material portion or

a surface of the metal portion, and the metallic material portion does not contact the overlying or the underlying insulating surface.

3. The three-dimensional memory device of claim 1, wherein:

the metallic barrier material portion comprises a conductive metallic nitride material; and

the metallic material portion consists essentially of elemental tungsten.

4. The three-dimensional memory device of claim 1, further comprising a backside trench vertically extending through the alternating stack and containing an insulating spacer at a periphery thereof, wherein:

an inner sidewall of the metal portion directly contacts the distal sidewall of the metallic barrier material portion and the distal sidewall of the metallic material portion;

a first vertical interface at which a proximal sidewall of the metal portion contacts the distal sidewall of the metallic barrier material portion and a second vertical interface at which the first metal of the metallic material portion contacts the cobalt of the metal portion are laterally offset from a sidewall of the backside trench contacting the insulating layers by a same lateral recess distance; and

at least a portion of an interface between an outer sidewall of the metal portion and the insulating spacer protrudes farther outward from the memory stack structure than interfaces between sidewalls of the insulating layers and the insulating spacer.

5. The three-dimensional memory device of claim 4, wherein:

the metal portion consists essentially of cobalt; and

a convex sidewall of the metal portion contacts a concave sidewall of the insulating spacer at the interface between the outer sidewall of the metal portion and the insulating spacer.

6. The three-dimensional memory device of claim 1, wherein the memory stack structure comprises:

a charge storage layer;

a tunneling dielectric located on an inner sidewall of the charge storage layer; and

a vertical semiconductor channel contacting an inner sidewall of the tunneling dielectric, wherein a blocking dielectric layer is located within the memory opening on an outer sidewall of the charge storage layer or between each vertically neighboring pair of an electrically conductive layer among the electrically conductive layers and an insulating layer among the insulating layers.

7. The three-dimensional memory device of claim 1, further comprising a backside blocking dielectric layer located between each vertically neighboring pair of an electrically conductive layer and an insulating layer, wherein:

each of the metal portion and the metallic barrier material portion contacts a bottom surface of an overlying portion of the backside blocking dielectric layer and a top surface of an underlying portion of the backside blocking dielectric layer; and

the metallic material portion does not contact the backside blocking dielectric layer.

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